

**STUDIES ON MITES ASSOCIATED WITH SELECTED
GROUPS OF AGRICULTURALLY IMPORTANT
INSECTS OF KERALA**

*Thesis submitted
in partial fulfillment of the requirements
for the award of Degree of*

DOCTOR OF PHILOSOPHY IN ZOOLOGY

By
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CERTIFICATE

This is to certify that the thesis entitled “**STUDIES ON MITES ASSOCIATED WITH SELECTED GROUPS OF AGRICULTURALLY IMPORTANT INSECTS OF KERALA**” is an authentic record of the work carried out by **Ms. Anjitha K Bhadran** under my supervision and guidance in partial fulfillment of the requirements of the Degree of Doctor of Philosophy in Zoology in the Division of Acarology of this Department and that no part thereof has been presented before for any other degree or diploma.

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DECLARATION

I, **Anjitha K Bhadran**, hereby declare that this thesis entitled “**STUDIES ON MITES ASSOCIATED WITH SELECTED GROUPS OF AGRICULTURALLY IMPORTANT INSECTS OF KERALA**” is an authentic record of the work carried out by me under the supervision and guidance of **Dr. N. Ramani**, Professor (Rtd.), Division of Acarology, Department of Zoology, University of Calicut and that no part of this has been submitted before for the award of any other Degree or Diploma.

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സംഗ്രഹം

മണ്ഡരി മറ്റ് കശേരുകളും അകശേരുകളുമുള്ള മൃഗ ഗ്രൂപ്പുകളുമായി വിവിധ തരത്തിലുള്ള സഹവാസം പ്രകടിപ്പിക്കുന്നു, രണ്ടാമത്തേതിൽ, പ്രാണികൾ പ്രധാന ഗ്രൂപ്പാണ്. സാധാരണ ആവാസ വ്യവസ്ഥകൾ പങ്കിടുന്നത് കാരണം കീട-മണ്ഡരി ഇടപെടലുകൾ വികസിപ്പിച്ചിരിക്കാം, അല്ലെങ്കിൽ ആകസ്മികമാകാം. പ്രതിപ്രവർത്തനത്തിന്റെ സംഭവങ്ങളും വ്യാപ്തിയും ഗണ്യമായി വ്യത്യാസപ്പെടുന്നു. മണ്ഡരി ഉൾപ്പെടുന്ന പ്രാണികളുടെ ആതിഥേയരുടെ രൂപശാസ്ത്രപരവും ജൈവപരവുമായ വൈവിധ്യത്തെ ആശ്രയിച്ചിരിക്കുന്നു. ഒരേ ആവാസവ്യവസ്ഥയിൽ സഹവർത്തിത്വവും പൊതുവായ ഭക്ഷണവിഭവങ്ങൾ പങ്കുവെയ്ക്കുകയും ചെയ്യുന്നതിലൂടെ മണ്ഡരി പ്രാണികളുമായി കൂടുതൽ സങ്കീർണ്ണമായ തരത്തിലുള്ള സഹവാസം സ്ഥാപിക്കുന്നു. അവ താൽക്കാലിക സ്വഭാവമുള്ളതും നിഷ്ക്രിയമായ ചിതറിക്കിടക്കുന്നതും അല്ലെങ്കിൽ സമ്പൂർണ്ണവും പരസ്പരവിരുദ്ധവും പരാനഭോജിയും ആയേക്കാം. പ്രാണികൾക്കും മണ്ഡരിക്കുമിടയിൽ കണ്ടുമുട്ടുന്ന വിവിധ തരത്തിലുള്ള കൂട്ടുകെട്ടുകളിൽ കീടങ്ങളുടെ ജൈവിക നിയന്ത്രണത്തിൽ പരാനഭോജിത്വവും വേട്ടയാടലും വിജയകരമായി പ്രയോജനപ്പെടുത്താം, അതിനാൽ കീടങ്ങളുമായി ബന്ധപ്പെട്ട മണ്ഡരികൾ പ്രാധാന്യം അർഹിക്കുന്നു. അതിനാൽ, കാർഷിക-ഹോർട്ടികൾച്ചറൽ പ്രാധാന്യമുള്ള ചില തിരഞ്ഞെടുത്ത ഇനം പ്രാണികളുമായി ബന്ധപ്പെട്ട മണ്ഡരി വൈവിധ്യമാർന്ന ജന്തുജാലങ്ങളെ പര്യവേക്ഷണം ചെയ്യുന്നതിനായി അതത് പ്രാണികളുടെ ആതിഥേയരുകളിൽ അവയുടെ വിതരണ രീതി പഠിക്കുന്നതിനായി, അതത് ആതിഥേയരുടെ കൂട്ടുകെട്ടിന്റെ സ്വഭാവം പര്യവേക്ഷണം ചെയ്യുന്നതിനായി, നിലവിലെ പ്രവർത്തനം ഏറ്റെടുത്തു. കീടങ്ങളുടെ ആതിഥേയരുമായി ബന്ധപ്പെട്ടിരിക്കുന്ന മണ്ഡരി വ്യത്യസ്ത ജീവിത ഘട്ടങ്ങൾ തിരിച്ചറിയുകയും തിരഞ്ഞെടുത്ത ഇനം

പ്രാണികളുടെ ജനസംഖ്യയെ അടിച്ചമർത്താൻ പരാനഭോജി/കവർച്ച മണ്ഡരി സാധ്യതകൾ പര്യവേക്ഷണം ചെയ്യുകയും ചെയ്തു. ഈ ലക്ഷ്യങ്ങളോടെ, ഇപ്പോഴത്തെ പഠനം കേരളത്തിൽ ഇത്തരത്തിലുള്ള ആദ്യത്തേതാണ്. ഇത് ഇന്ത്യയിലെ മറ്റ് ഇന്ത്യൻ സംസ്ഥാനങ്ങളായ പശ്ചിമ ബംഗാൾ, തമിഴ്നാട്, ഹരിയാന എന്നിവിടങ്ങളിൽ നിന്ന് ഇതുവരെ ശേഖരിച്ച പ്രാണി- മണ്ഡരി കൂട്ടുകെട്ടുകളെക്കുറിച്ചുള്ള കൂടുതൽ വിവരങ്ങൾ ചേർക്കാൻ സഹായിക്കുന്നു. 24 ഇനം പ്രാണികളുടെ ആതിഥേയത്വമായി ബന്ധപ്പെട്ട 65 ഇനം മണ്ഡരി രേഖപ്പെടുത്താൻ ഈ പഠനം സഹായിച്ചു, അവയിൽ പത്ത് ഇനം ശാസ്ത്രത്തിന് പുതിയതായി കണ്ടെത്തി. ഒരു പുതിയ ഇനം മണ്ഡരി, ഹിസ്റ്റിയേസ്സോമ ഫറോവയുടെ ജീവിത ചക്രം പഠനങ്ങൾ ഒലോഞ്ചിക്കോളിസ് എന്ന ആതിഥേയനുമായുള്ള ബന്ധത്തിന്റെ നെക്ട്രോമെനിക് ഇനം രേഖപ്പെടുത്താൻ പ്രാപ്തമാക്കി. കൂടാതെ, പുതിയ മണ്ഡരിയായ പോടാപോളിപ്പസ് പാലപ്പറമെൻസിസ് നെല്ലിന്റെ കീടമായ ഓക്ലിയ ഹൈലയിൽ പരാനഭോജനത്തിലൂടെ ഉണ്ടാക്കുന്ന ആഘാതം മനസ്സിലാക്കാനും പഠനം സഹായിച്ചു. ലസിയോഷിയസ്സ് മൂലം കഡൻസിസ് എന്ന പുതിയ ഇനം മണ്ഡരി മുളകു ചെടിയെ ബാധിക്കുന്ന വെള്ളയീച്ചുകളിൽ ഉണ്ടാക്കുന്ന ആഘാതത്തെ പറ്റിയും പഠിച്ചു.

Human temperament to traverse into the bewildering diversity of earth has revealed the existence of over 2.3 million species (according to the catalogue of life, 2023) including plants, bacteria and animals. Another 7.5 billion species await discovery among the estimated 1 trillion species (according to the National Science Foundation, 2016) existing on earth foreshadowing the never ending quest of human to explore the biodiversity. Many of the organisms among the above estimated list lack the status of a 'hero-species,' being overlooked by many as minute and paltry. However, the chain of nature is intricately woven to include all the hidden species assemblage. Invertebrates contribute to more than 1.25 million discovered species, of which over 84% is represented by the phylum Arthropoda.

The subclass Acari includes a highly successful and the largest group of chelicerate arthropods forming an interesting offshoot of the class Arachnida. Recent molecular evidences suggest them to be a sister taxon of the clade comprising insects and crustaceans. Acarines are distinguishable from the related arthropod taxa by lacking features like antennae, wings, distinct head and by possessing four pairs of legs. Mites have invaded almost all available habitats of the terrestrial, freshwater and marine ecosystems. The freeliving Acari includes herbivores, saprophages, fungivores, algivores and microbivores while the parasitic group includes 'ecto' and 'endo' parasites of vertebrates and invertebrates, each possessing various adaptive features for their successful existence. The ability of mites to establish in every habitat that can support their life justifies the enormous diversity of this group that no other invertebrate groups can outnumber.

The clade Acari is assumed to be monophyletic with two composite lineages; Parasitiformes and Acariformes, designated by giving the status of superorders (Krantz and Walter, 2009). The Parasitiformes includes four orders like Opilioacarida, Holothyrida, Ixodida and Mesostigmata while the Acariformes comprises two orders; Trombidiformes and Sarcopiformes. The order Mesostigmata is a large assemblage of Parasitiformes mites comprising three suborders and approximately 70 families, with the members colonising different habitats as free living predators, parasites or

symbionts of vertebrates and invertebrates. The order Trombidiformes includes two suborders; Sphaerolichida and Prostigmata, the latter being diverse with predators, parasites, phytophages, saprophages and paraphages. The order Sarcoptiformes includes the cohort Astigmatina, with its members being the acarofaunal component in both patchy and ephemeral habitats. The astigmatine group exhibits highly specialised deutonymphal stage modified for hitch-hiking. Mites of all groups depend on either this active form or the passive form of dispersal which is a key for population survival. Passive dispersal is usually achieved by aerial currents while active dispersal involves seeking out a substratum for movement from one region to the other. While many deutonymphs and adults of mesostigmatine family establish phoretic relationship without possessing specialised morphological features, some of the mesostigmatid members exhibit specialised dispersing forms called 'phoretomorphs' which are morphologically and behaviourally adapted for phoresy.

The most studied among the acarine invaders of terrestrial habitat are the parasites of plants as these phytophagous mites act as pests of both indoor and outdoor agricultural ecosystems. Majority of the phytophagous mites are grouped under the suborder Prostigmata in which the most important pest families like Tetranychidae, Tenuipalpidae, Tarsonemidae and Eriophyidae are present. Feeding activity of mites brings out alterations in the plant micro and macro-nutrients thereby reducing the crop yield. Mites of the family Acaridae are important stored product pests, apart from being destructive pests of agro-ecosystems. The Ixodidae, Argasidae and some Dermanyssoid families are hematophages, some of them serving as vectors of contagious diseases.

The beneficial role of mites surmounts the fatal effects caused by them as they contribute to the biodegradation of organic residues, biological control of invertebrate pests, bio-indication of ecological conditions and by serving as an essential link in the food webs by feeding on nematodes, small annelids, collembolans and microarthropods. The parasitic and predatory modes of life style adapted by the mites makes them beneficial to humans thereby reducing the need for chemical control measures to suppress the invertebrate pests of agricultural and ornamental crops.

Agriculture has been an essential part of human civilisation ever since the evolution crossed the Stone Age, i.e, the Neolithic era. It is the backbone of the economic system

of a country, especially of a developing country like India. There are many potential threats to agriculture which include climate change, biological invasion, pest attack and decrease in soil fertility. The estimated loss in agriculture due to pest attack exceeds 50% in several crops like wheat and cotton (Oerke, 2012) which call for an urgent need of pest control measures. Despite the increase in use of pesticides, crop losses have not decreased globally. The adverse impact of pesticides on the environment and the increasing cases of pesticide resistance demands the need for a threshold concept for crop management. Biological control of pests relies on predation, parasitism or other natural mechanisms to suppress the pest population. It showcases the need for finding out the predators and parasites of pest population occurring naturally in the field. This method is eco-friendly and also boosting up the natural enemy complex and thereby strengthening the existing food web.

About 18% of the damage in global agricultural production is caused by herbivorous insects. Insects represent an important group of the phylum Arthropoda, constituting about 66% of the animal species (Zhang, 2011). The varying adaptations of insects to invade different habitats create bewildering diversity in this group and make them perfect competitors in the race for survival. Insects damage the crops in two ways, primarily by feeding on the plant tissues thereby reducing the surface area available for photosynthesis and also distort the plant growth, creating an overall reduction in the yield. The indirect damage is caused by the transmission of pathogenic infections. Some insects are polyphagous while some are restricted to a particular crop. All stages of the pest do not necessarily damage the crop, usually the larva forms the damaging stage as in many cases of Lepidoptera and Coleoptera but in the case of sucking hemipteran pests and in herbivorous pests like Orthoptera, adult stages are also destructive. Besides being harmful to agriculture, insects serve as an inevitable component, promoting agricultural ecosystem in many ways. Some of the ecosystem services provided by insects in agriculture include nutrient cycling, seed dispersal, pollination, pest control etc. The decomposition of both plant and animal materials like litter, dung and carrion is very important in the ecosystem process which is mainly done by insects.

The largest order in the class Insecta is Coleoptera with over 3, 60,000 described species (Purti *et al.*, 2018). This is the only order with the forewings hardened and modified into elytra which enable them to survive in any type of habitat, ranging from

desert to aquatic systems. The members of this group undergo complete metamorphosis with egg, larva, pupa and adult stages. The mouthparts are chewing type with different food habits depending on their habitat. Some feed on plants and fungi, some are carnivorous and a few are parasitic on other organisms. Most of the coleopteran families are important pests of agriculture, horticulture and forestry. The adult and larval stages of families like Chrysomelidae and Coccinellidae feed on the foliage of crops like Cucurbitaceae, Solanaceae and Brassicaceae (Menezes *et al.* 2005, Ahmad *et al.* 2020). The members of the family Scarabaeidae are notorious pests of agriculture, forestry and horticulture. Mostly, the scarab beetle larvae feed on the roots and the adults feed on the aerial parts of plants (Jackson and Klein, 2006). Several endemic species of scarab beetles like the members of the genus *Oryctes* cause damage to the palm crops, creating a great economic loss.

The family Curculionidae (snout beetles) is arguably one of the largest families of Coleoptera with more than 50,000 species which comprises the diverse families of phytophagous pests of field and orchard crops. Curculionid members of the genus *Rhynchophorus* have been recognized as notorious pests worldwide and especially in tropical countries where the economy is dependent on palm crops. Species like *Odoiporus longicollis* and *Cosmopolites sordidus* are other important pests coming under this family. Both of the species are pests of banana causing damage to the pseudostem and corm respectively. Yet another important family of Coleoptera is Cerambycidae with over 35,000 described species. *Batocera rufomaculata*, commonly known as the mango stem borer coming under this family forms a key pest of mango and cashew in Southeast Asia. Another species of Cerambycidae, *Xystocera globosa* is an important pest of woody trees. The coleopteran family Tenebrionidae commonly known as the ‘darkling beetle’ comprises important pests of both living and dead trees. Some common storage pests are also included in this family. The larvae of *Gonocephalus* spp., lesser false wireworm feed on the stems of paddy seedlings, leading to the plant wilt. The genus *Gonocephalus* comprises some important wood boring pests. While rotten wood forms habitat for some species of *Gonocephalus*, some other species attack on the dead tissue of live trees.

Lepidoptera is the second largest insect order after Coleoptera with over 1, 80,000 described species of moths, butterflies and skippers. With their coloured and appealing wing and body pattern, the members of this group are of aesthetic

importance. As pollinators of diverse plant families, most of them are considered as beneficial insects. On the other hand, the larval stages of Lepidoptera, i.e caterpillars are defoliators and miners of some economically important plants. Another important group of herbivorous insects comes under the order Orthoptera, the members of which mainly feed on foliage and rarely on roots. Acrididae is a predominant family of the order, comprising the short horned grass hoppers. Some species of grasshoppers are usually solitary but under some circumstances their population level goes very high that they become gregarious and uncontrollable. Locust swarming is a nightmare for the farmers which sometimes turn out to be the cause of many famines and human migrations. *Oxya* forms an important genus comprising acridid pests which are not considered as key pests of paddy but under certain conditions of altered land use pattern, they might be raised to the level of key pests. In the north-east parts of India, members of the genus *Oxya* are given the status of key pests.

Termites are social insects coming under the order Blattodea and infraorder Isoptera. Subterranean termites are important household pests which bore on the wood. Many groups of termites are pests of agriculture. They can bore into the groundnut pods causing great loss in yield. Some of them make termite nests on upright trees and fruit crops like banana which reduces the yield.

Hemiptera is the insect order with diverse array of insects differing considerably in food habits and life histories. The members of this group are economically significant plant pests which damage the crops by feeding on the phloem sap. Most common hemipteran pests which cause damage include aphids, whiteflies, stinkbugs, planthoppers etc. (Koch *et al.*, 2016). Their ability to achieve high population growth and potential to transmit viral diseases makes them notorious pests. Whiteflies constitute an important group of polyphagous pests coming under this order. This hemipteran pest comes in the forefront of the most damaging pests of the world due to its polyphagous nature and the wide spectrum of damage caused to host plants. The direct damage by the white fly is induced by its sucking mouthparts which remove sap from the phloem of plants. The indirect damage results due to the excretion of honey mildew, inviting the fungus growth and by vectoring of many plant viruses (Perring *et al.*, 1993; Kedar *et al.*, 2014).

Dung beetles are important indicators of good pasture health. They drive the ecosystem processes like nutrient recycling, soil aeration, bioturbation, secondary seed burial and parasite suppression (Nichols *et al.*, 2008). Besides these, the ecosystem services provided by the beetles make them an obligatory component of pasture ecosystem. Steinfeld *et al.* (2006) reviewed the economic role of dung beetles in maintaining sustainable livestock production. As the dictionary meaning of the word ‘agriculture’ goes like ‘the science or practice of farming, including cultivation of the soil for the growing of crops and the rearing of animals to provide food, wool, and other products’, dung beetles undoubtedly form the backbone for agricultural production worldwide.

Insect-mite interactions are possibly accidental which might have developed due to the sharing of the same habitats. The prerequisite for every species interaction is the co-occurrence of two or more organisms. Sharing the same habitat offers the best ground for the origin of varied types of interactions, mostly symbioses, which becomes vital for initiation of further evolutionary studies on the characteristics of the habitats which are shared by many insects and mites. Okabe (2013) defined symbiosis as species interaction in which two organisms live together though the term in strict sense is used for mutualism. The author further classified the relationship called ‘symbiosis’ into phoresy, parasitism, mutualism, inquilinism and commensalism. The most common relationship that mites belonging to Astigmata, Mesostigmata and Prostigmata make with insects is phoresy. Phoresy was primarily defined by Lesne (1896) as those cases in which the transport host serves its passenger as a vehicle. He envisaged this relationship as temporary and loose in which the relationship ended as soon as the traveler disembarked in a suitable location. Farish and Axtell (1971) defined phoresy as the phenomenon where ‘one animal actively seeks out and attaches to the surface of another animal for a limited period of time during which the attached animal ceases both feeding and ontogenesis. Cheng (1991) envisaged phoresy as a symbiotic relationship. Though some of the adaptive traits of dispersal like host seeking, recognition of host signals and specificity in the sites of attachment overlap with the parasitic behavior, phoresy can be easily distinguished by the occurrence of a quiescent stage. Phoresy can either be facultative or obligatory. Mites occurring in ephemeral habitats like mushroom, small carcasses etc. show facultative phoresy since density dependent factors induce migrations. Obligatory phoresy is seen in mites

occurring in substantial habitats like manure piles or caves where seasonal migrations are necessary.

The relationship of phoresy was later identified to be detrimental to the host. The high phoretic load was found to impede the flight ability of the host. Athias-Binche (1993 a) speculated the transition of phoretic relationship to parasitism exemplified by the frequent occurrence of both phoretic and parasitic forms in mites and nematodes. Moving on through the evolutionary pathway, it was found that the phoretic non feeding stage of an astigmatid mite, *Hemisarcoptes cooremani* acquired the haemolymph of its host beetle, *Chilocorus cacti* (Houck and Cohen, 1995) which supported the notion of phoresy being evolved to parasitism.

Phoresy is highly manifested in many orders of Acari, which often manifests phoretic specificity. The members of different groups of Acari are specialized in various ways to attach on the host surface. In the order Mesostigmata, the phoretic uropodine deutonymphs attach on the arthropod cuticle with anal pedicel while some of the uropodines and microgyniines exhibit phoretomorphs which are specialized stages meant for dispersal. Oribatid mites also often engage in passive dispersal usually on beetles. In Astigmata, facultative heteromorphs are very common, referred to as ‘hypopi’.

Parasitism is defined as ‘the use of one organism, the host as both habitat and a source of nourishment by another organism, the parasite.’ Acarine parasites can damage their hosts by causing loss of reproductive potential, tissue irritation, and reduction in longevity. Krantz (2009) reviewed that the mites present in respiratory, subcutaneous and alimentary sites of the host are endoparasitic while those present under the elytra, hindwings or inter-segmental membranes are ectoparasitic. In this way, the different stages of mites which feed on the haemolymph of insects, for example, family Erythraeidae, Trombidiidae etc. are classified as parasitic. Like the phoretic adaptations that mites possess, parasitic adaptations do exist in several forms. While reviewing the adaptations in parasitic mites, Fain (1994) listed many factors like multiple speciation, variability, specificity, co-evolution and regression as important in the evolution of parasitic mites. The parasitic mites do not directly kill the host but can reduce the host viability to a large extent.

Predatory acarine fauna occur in diverse habitats ranging from the soil-litter to the forest canopy. Predatory mites exist in the orders of Mesostigmata, Trombidiformes and Sarcoptiformes. Predatory soil mites are encountered in all levels of soil-litter column where they feed on nematodes, small arthropods, rotifers and many small soil invertebrates. Krantz (2009) listed the common families of the order Mesostigmata, Trombidiformes and Sarcoptiformes showing predation in soil and litter. Mesostigmatid families encountered in soil and litter habitats include Parasitidae, Macrochelidae, Digamasellidae, Laelapidae, Ascidae, Macrochelidae, Zerconidae, Uropodidae etc. Some of the prostigmatid representatives of predatory acarine fauna include Eupodidae, Rhagidiidae, Bdellidae, Labidostomatidae, Stigmaeidae and Cheyletidae. Soil inhabiting predators of the order Sarcoptiformes occur in the suborder Oribatida and family Acaridae. The predatory mites are also encountered in the aerial portion of plants. These predators feed on different stages of insects and mites. Members of the family Phytoseiidae, Ascidae, Blattisociidae and Cunaxidae belonging to the order Mesostigmata predate on phytophagous mites, whiteflies, scale insects and other arthropods. Trombidiformes families like Stigmaeidae, Tydeidae, Cheyletidae, Anystidae, Cunaxidae and Erythraeidae are known to be effective predators of orchard pests (Krantz, 2009).

An investigation on the accurate relationship between mites and insects is highly warranted as in one way or other it would help in fulfilling the unending quest of the mankind to explore the ecological relationship existing between two diverse groups of species. Exploring the predatory and parasitic relationship between insects and mites also justifies the use of mites in the biological control of pests. The term pest is used very specifically by agriculturists; in the ecological perspective ‘pest’ does not exist. Pests arouse out of the intolerance of human beings to other animals occupying their space when they modified the environment for their own well being. Gerson *et al.* (2003) defined pests as ‘invertebrates that harm their plant or animal hosts to some economic extent, impairing the health of humans or domestic animals.’ In the present work, the word insect pest refers to all insects which do harm to the agricultural crops and reduce the economic yield. Every organism in nature is created with a justifiable rationale so that the dispensable growth of an organism, to be more specific a ‘pest’ is restrained by the naturally occurring predators/parasites/parasitoids but human eye

is often predisposed to the macro-organisms during a search for biocontrol agents as is the case of unnoticed micro acarine biocontrol agents.

The present work was taken up with an intention to explore the diverse faunal groups of mites associated with selected species of insects of agricultural/horticultural importance, by specifically focusing on the distribution pattern of mites on different parts of insect body, the nature of insect- mite associations, identifying the different life stages of mites associated with insects, conduct of life cycle study of phoretic representative to identify the nature and precise type of association between the host and phoront and to trace the potential of parasitic/predatory mites to suppress populations of selected species of insects. With these objectives, the study forms the first of its kind from Kerala and it is envisaged to add new data to the existing knowledge on insect-mite associations available in India, from states like West Bengal, Tamilnadu and Haryana. Elucidation of potential of mites in the biological control of insect pests still remains as a very poorly explored area, especially in South India where majority of the people rely on agriculture to meet their livelihood and hence the present study was focused on this aspect too.

Chapter 1

Introduction

Exploration of biodiversity is always an area of interest in the field of biological science. Besides satisfying human pursuit, an authentic knowledge on biodiversity and taxonomy is important in the present scenario where the earth is in the verge of species extinction and habitat loss. Without having a sound knowledge in taxonomy, an effective decision cannot be made towards the conservation of biodiversity and sustainable use of natural resources. Taxonomy thus forms the foundation of biodiversity conservation, pest management, medicine, fisheries, bio-prospecting, quarantine, defence etc. Species with considerable size and aesthetic value comes in the forefront when a question of biodiversity conservation arises. Some insect species assemblage also seeks attention since many of them have gained the status of pests and natural enemies. An important group of arthropods being overlooked despite its abundance and economic importance is the subclass Acari. Regardless of the importance of these tiny arthropods in diverse ecosystems as decomposers, pests, predators, parasites, bioindicators etc., majority of the acarine fauna still awaits discovery in India especially in a South Indian state like Kerala. Owing to the wide neglect experienced in the field of taxonomy, especially in the acarine taxonomy, a considerable research gap can be found in the studies related to faunal diversity and systematic descriptions of acarine fauna.

Among the very few studies undertaken so far in Kerala on mites, the prime focus was given to the elucidation of the pest status of mites. The association of mites and ticks with vertebrates often attracted the attention of scientists working in the veterinary and medical sciences; the acarine interaction with invertebrates is rather a very less explored area. Majority of the invertebrate associations that mites make is with arthropods, within which over 90% is with the members of the class Insecta. Being evolved in the Devonian era, one can foresee a simple association like phoresy between insects and mites. This relationship might have later evolved into still complex forms of relationships like necromeny, parasitism and predation. Majority of the insect-mite associations are symbiotic or commensalistic. Among these associations, some are fluid over time as with the case of phoresy being evolved to

parasitism. Understanding the insect-mite association is important as some of the mites exhibiting parasitic or predatory relationship with insect pests could become beneficial to man kind in future as natural enemies, exerting tremendous impact in biological control.

Phoresy, the most studied type of insect-mite association, was initially defined as a 'loose, inter-specific association which ends up once the phoretic debark from the host'. More complex definitions for phoresy were also encountered as the relationship was further investigated in detail. Initially, being regarded as a commensalistic relation where the phoretic organism gained benefit without harming the host, phoresy was later redefined (Athias-Binche, 1994) as a particular form of parasitism. Moreover, this relationship was found fluid over time. Phoresy often leads to parasitism by increasing the phylogenetic specificity and synchrony with the host life cycle. According to Waage (1979) two types of evolutionary routes to parasitism exist, Type A and Type F. The adaptations for association between a parasite and its host precede the adaptations for feeding in Type A. In Type F, adaptations that would eventually allow feeding on the host precede the adaptations for association. Parasites that evolved through the 'Type A' pathway typically have free-living nidicolous relatives and clearly have secondarily evolved mouthparts adapted to feed on host products. Followers of the Type F pathway have the right mouthparts in the first place but only secondarily develop an association with the host. Many authors describe lineages of parasitic mites evolving from nidicolous ancestors (Type A route). This notion was further evidenced by the occurrence of a relationship called necromeny where the phoretic stage of the host doesnot leave the host, rather waited for the adult to die only to molt into the next stage to feed on the carcass of the host. Houck and Cohen's (1995) experiments with astigmatine deutonymph of *Hemisarcoptes cooremani* and its carrier beetle, *Chilocorus cacti* made the relationship of phoresy more complex since the authors could recover tritiated water from the hindgut of the deutonymph which was thought to be acquired from the haemolymph of the host. Furthermore, the beetle's haemolymph was found as a prerequisite for the further molt of the deutonymph. The authors finally concluded the relationship as a kind of parasitism since feeding from its host and the inevitable need of the beetle for its further development forecast a parasitic way of life cycle.

Astigmatid mites exhibit a specialized stage called 'hypopus', equipped for phoresy. Houck and Cohen (1995) believed that this stage is a result of co-evolution between a phoront and its associate and could be considered as a link between free-living ancestors and future parasites. 'Phoretomorphs' are morphologically distinguishable stages exhibited by some uropodines and microgyniines which are entirely different from the sedentary deutonymphs. Adult females also exhibit phoretomorphy as in the case of *Antennoseius*. In an insect-mite association, phoronts prefer to attach on different body parts of the insect. This area of attachment differs as the insect host varies. *Dinogamasus* phoretic on the beetles usually prefer to attach on the thoracic hairs while when they disperse on the bees, they are found in specialized pouches called acarinarium. Phoretic acarine associates are present on well defined body parts in many cases of insect-mite phoretic relationship. The subelytra of coleopterans serve as safe haven for many phoretic mites. Likewise, the basal part of proboscis of lepidopteran members harbor phoretic mites. A considerable number of acarine phoronts prefer to attach on the hindwings of Orthoptera. All the above parts offer protection to the phoronts as well as prevent dislocation of mites during the host's flight. In bees and wasps, there are specialized structures called acarinarium which harbor dispersing mites. The development of specialized structures on the insect body to carry mites can be speculated as an evidence of their symbiotic relationship. However Klimov *et al.* (2007) hypothesized that the acarinarium in social bees tend to concentrate unwanted mites, thereby reducing the chance of their dispersal to other brood members. Phoretics in higher abundance can also directly impede the activity of the host. It is known to reduce the flight in some members of Coleoptera and Diptera. The necromenic association of a phoront on its host is observed in phoretic astigmatid mites like *Histiostoma* and *Sancassania* (Wirth, 2009; Al-Deeb *et al.*, 2011). The life cycle studies of these mites are very important in determining the exact nature of association.

Parasitic mites of insects are ubiquitous in distribution and have been isolated from many insect orders like Orthoptera, Coleoptera, Diptera, Hymenoptera, Hemiptera and so on. In the case of parasitic water mites like Arrenuridae, Anystidae and Hydryphantidae, the larva detaches from the host after feeding on the haemolymph, leaving scars of parasitism on the body of its insect host. Here all the developmental stages cannot be recovered from a single host body. There are cases in which all the

developmental stages starting from egg to adult could be recovered from the infested body of the insect. Examples include members of Podapolipidae like *Podapolipus*, *Tarsopolipus*, *Eutarsopolipus* and some Acaridae like *Tyrophagus*. Also included in this list are some endoparasitic mites like *Locustacarus*, *Ovacarus*, *Acarapis woodi* etc. Though parasitic mites do not kill their hosts, the longevity and vigour of the host insects will be reduced considerably.

Acarine predators feed on different stages of insects like whiteflies, scales, tiny insects, phytophagous and saprophytic mites. Most of the predatory mites are food generalists, capable of feeding on diverse preys and also plant resources like pollen, nectar and fungi. This nutritional diversity support their survival in agro-ecosystems, even on alternative food items other than their prey, which make them efficient natural enemies. Members of phytoseiidae are being observed as efficient predators of agri/horticultural pests. Leaf characteristics like domatia and hairiness can affect the density of predatory mites, especially some species of phytoseiids. Therefore, non-crop plants which can support the existence of predatory mites are recommended along with the crop plants as a strategy to conserve the predatory populations under field conditions.

The biodiversity of insect associated mites of India is very poorly explored and hence the existing knowledge on the above aspect is scanty, except a few isolated reports available on the incidence, faunal diversity as well as taxonomic descriptions of various species including the new species of insect associated mites from West Bengal, Maharashtra and Tamil Nadu, but information on their biological aspects is mostly lacking. Presently, no data are available on the insect associated mites of Kerala, and not even a single species has been reported so far from this state, though a basic knowledge on the life stages of insect associated mites as well as the nature and extent of different types of their interaction with insect hosts etc. is highly essential and noteworthy in an agricultural state like Kerala, especially in the context of biological control of agricultural pests using their natural enemies. In order to fill up the above lacunae, the present investigation was undertaken to gather information on the species composition, taxonomy, ecology, distribution, types of interaction between mites and insect hosts, life cycle details of dominant mite associate, biocontrol potential of selected species of mites on their respective hosts etc. The present part of the thesis deals with the acarine faunal diversity associated with insect

hosts of agri-horticultural importance, through extensive surveys undertaken in various localities selected from four different districts of Kerala. Data were also incorporated on the varied types of relationship between the mites and their respective insect hosts, distribution pattern on varied body parts of the insect hosts and life cycle studies of a new species of *Histiostoma* exhibiting a necromenic relationship on its weevil host, *Odoiporus longicollis*. The impact of phoretic mite load on the body weight of some selected species of weevil hosts was also discussed in the present part.

Chapter 2

Review of literature

Insects constitute the most species rich group of animals on the earth, with their representation extending over 70% of the total animal diversity and playing many vital roles in driving the ecosystem functions as pollinators, natural enemies and numerous other functions. Having been recognized as the “hyperdiverse groups”, insects and mites form the major intrinsic elements of many ecosystems, and their frequent co-existence, in temporal/ transitory/ both modes would result in the genesis of diverse types of interactions. Quite often, such biological relationships between species would get reflected in varied levels, ranging from the most simple to the more complex, with overlapping ranges in several instances. However, despite their ecological/evolutionary/application levels of significance, much of the biological relations between insects and mites still remain quite unexplored or very poorly explored and in India, with the exception of a few scattered information on the incidence, faunal diversity and types of associations between mites and insects available from states like Tamil Nadu, Haryana and West Bengal, this represents a quite unexplored realm of research. The present investigation thus forms the first attempt from Kerala pertaining to studies undertaken hitherto on diverse aspects of insect -mite associations including the elucidation of faunal composition and species description of insect associated mites, regional preference and specificity of acarine associates on the body of host insects, and the varied types of associations and their consequent impact on the host insects.

Since the pioneering work on insect-mite association by Linnaeus (1758) in the 18th century published in his famous publication of the 10th edition of *Systema naturae*, several researchers initiated attempts to study the incidence and types of insect-mite associations in several countries of the world. Since then, several authors, based on the frequent spatial or temporal co-occurrence of insects and mites made extensive contributions to elucidate the diverse types of interactions, mainly the symbiotic types of interactions between species, ranging from mutualism to commensalism and antagonism. Of these, the well established associations so far elucidated between the

insects-mites were diagnosed as phoresy, parasitism and predation, with occasional overlapping ranges. Based on the above categorization, the review of literature presented here has been split to arrange the important findings on insect-mite associations under the major divisions like phoresy, parasitism and predation.

Phoresy

Phoresy, as formally defined by the author Lesne (1896), could be designated as a loose association between a carrier and a passenger, subjected to limitation once the passenger got disembarked from the host. Phoretic association was reported among different orders of insects and the members of acarine orders like Mesostigmata, Trombidiformes and Sarcoptiformes. Berlese (1910) described species belonging to the Sarcoptiformes genus as phoronts on different species of *Batocera*. He further described the phoretic species, *Canestriniella amplexans* collected from *B. hector* and *C. togata* from *B. lunata*. Deegener (1917) coined the term 'symphorium' to refer to 'phoretic association' where more permanent associations like anemones on crab were quoted by the author rather than temporary associations.

Oudemans (1936) observed that the deutonymphs of the species belonging to the mesostigmatid family Uropodidae achieved phoretic mode of life style by means of an anal pedicel to establish attachment with their hosts. The deutonymphs of mites belonging to the genus *Hemisarcoptes* were found to exhibit phoretic association with the coccinellid beetle, *Chilocorus sigma* as observed by Bartlett and DeBach (1952 a) in California. The phoretic habit of the ascid mite, *Melichares monochami* on the sawyer beetles was reported by Lindquist (1962) and the author recorded that the position of hitch-hiking was restricted to the metathoracic spiracular atria of the beetle. Soper and Olson (1963) collected phoretic mites belonging to 11 genera (*Digamasellus*, *Longoseius*, *Proctolaelaps*, *Melichares*, *Uropoda*, *Sancassania*, *Tyrophagus*, *Troupeauia*, *Histiostoma*, *Thyreophagus* and an undetermined genus) and seven families from the sawyer beetles. Studies made by Faasch (1967) revealed that the anal pedicel in the deutonymphs of mesostigmatid mites was formed from a secretion of a gland located dorsally over the colon, which was initially present in the liquid consistency and got solidified upon contact with air. The remnants of the attached anal pedicel retained even after the detachment of the deutonymph from the beetle hosts. An earlier report on mites associated with different instars of the coconut

pest, *Oryctes rhinoceros* was made from Western Samoa by Hinckley (1967). The author reported two species of mites, one was a species of *Fuscouropoda* identified as a phoront on the adult stage and the other one was *Coleoplaelaps* sp. found in association with all life stages of the beetle. Information on the phoretic association of four species of mites viz., *Histiogaste ranops*, *Histiostoma* sp., *Digamasellus* sp. and a podapolipid member infesting the pales weevil, *Hylobius pales* was provided by Thomas *et al.* (1967) from England. An extensive review on the mites associated with nearctic scolytid beetles was prepared by Lindquist (1969 a) and the author stressed the importance of studying acarine associates of bark beetles as well as the biology of the mite. From India, Manjunath *et al.* (1969) reported five species of mites associated with the grubs, pupae and adults of *O. rhinoceros* viz. *Coleolaelaps rhinocerotis*, *Anoplocelaenoa plygyna*, *A. polytricha*, *Zygozeus imitans* and *Coleopterophagus procerus*. Though the exact relationship between the mites and *O. rhinoceros* was not properly identified, the authors speculated the relationship with *C. procerus* as parasitic and the rest as phoretic. Farish and Axtell (1971) restricted the usage of the term phoresy to denote mere temporary associations and redefined it as a phenomenon in which one animal actively sought out surface of another animal for a limited period of time, for the purpose of dispersal during which all processes of ontogenic development of the attached animal ceased temporarily. Later, when the association between the carrier and phoretics was studied in detail, it became difficult to define phoresy. Many studies came up with the view that phoresy was a kind of parasitism. Reviews on such studies were made after making some more reflections on phoresy and its ecological aspects.

Observations made by Moser and Roton (1971) revealed profuse number of mites associated with bark beetles. A total of 96 species of mites were recorded by the authors from bark beetles of Allen Parish. The Southern pine beetle, *Dendroctonus frontalis* was found to carry 57 species of mites, between trees in East Texas. Fain (1974) erected a new genus and a new species of astigmatid mite belonging to the family Histiostomatidae viz. *Curculanoetus rhynchophorus* based on its deutonymphal stage, which was found phoretic on the weevil pest, *Rhynchophorus phoenicis* from Belgium. The adult stage of the mite still remains unknown as it could be recovered from any of the countries so far. Treat (1975) reported over 90 species of phoretic mites, mainly belonging to the superfamilies Trombidioidea and

Erythraeoidea were reported by Treat (1975) in association with moths and butterflies. Lindquist (1975) speculated the early association of insects and mites from the late Mesozoic era. He further summarised that during the late Mesozoic era, the evolution of mites underwent an explosive radiation in conjunction with the insects which could have resulted in the developing loose and close relationships between them, ranging from mutualism to commensalism and antagonism. The insect-mite associations like phoresy and parasitism were well established in both the superorders, Parasitiformes and Acariformes of the subclass Acari.

Moser (1976) surveyed the phoretic mites associated with Southern pine beetles, using sticky traps, and he studied the percentage of mite infestation as well as the body part preferred by the phoronts. The results of his study revealed that the most preferred body region of seven species of mites was the subelytra of the host beetles. Phillipsen and Coppel (1977) described a novel species of phoretic mite viz. *Uroobovella formosona* from the abdominal tergites of the workers and soldiers of *Coptotermes formosanus*. The mite was found attached to the body of its termite host using its anal pedicel. They also reported an acarid member *Acotyledon formosani* associated with subterranean termite, *C. formosanus*. Phoresy often would facilitate dispersal of Trombidiformes mites, especially among members of Heterostigmata in which the adult females, apart from the deutonymphal stages also were found to enjoy phoretic dispersal, unlike the astigmatids and mesostigmatids. Binns (1979) observed that the phoretomorphs were equipped with thickened legs as in *Scutacarus basitarsus*, which appeared to be phoretic on the phorid fly, *Megaselai halterata* and exhibited perching behaviour to mount on the host body. The same author later (1982) reported that most of the mesostigmatid mites accomplished phoretic dispersal by means of their anal pedicels. Bridges and Moser (1983) observed that quite often, the mites were equipped with specialized integumental structures to carry spores as seen in the case of *Tarsonemusips* and *T. krantzi* which were phoretic on *D. frontalis* and which possessed sporothecae to transport ascospores. Moser and Bogenschutz (1984) recorded 38 species of phoretic mites associated with the spruce bark beetle, *Ips typographus* in Germany. Studies made by Wallace and Holm (1985) enabled to record the association of mesostigmatid mites with dung beetles, in which the abundance of the members of Macrochelidae was found variable depending upon seasonal variation. His study was focused on two species of *Macrocheles* viz. *M.*

merdarius and *M. glaber* and it was found that the latter was active during early summer while the former was active during early summer and early autumn. Wallace (1986) reported the association of 30 species of phoretic mites of the genus *Macrocheles* with Australian dung beetles. Two new species of mites belonging to the family Rhodacaridae viz. *Laelaptonyssus lenzi* and *L. darwiniensis* were described by Halliday (1987) from the nests of two Australian species of termites, *Coptotermes lacteus* and *C. acinaciformis*. The oldest record of mesostigmatid mite association with insect was that of a uropodid mite which was found attached to bark beetle, recovered from Dominican amber 20-40 mya as pointed out by Hunter and Rosario (1988). Studies undertaken by them also revealed the phoretic association of 25 species of mesostigmatid mites with termites and termite nests. Fain (1989) described phoretic mite species, *Afroheterozerconan coratus* belonging to the family Heterozerconidae collected from the nest of termites.

A new species of phoretic trigynaspid mite, *Diplogynium oryctae* was described by Vishnupriya and Mohanasundaram (1988) from Tamil Nadu, India and which was found associated with the coconut pest, *O. rhinoceros*. The same authors reported an acarine associate, *Grandiella batocerae* of the family Canestriniidae from *Batocera rufomaculata* from the same region. Studies carried out by Hunter and Rosario (1988) clearly showed that the primary hosts for mesostigmatid mites were the insects belonging to orders like Coleoptera, Hymenoptera, Diptera and Lepidoptera with which more than 93% of all the known associations were made. A new species of phoretic mite, *Athogavia borneoica* belonging to the family Canestriniidae associated with *O. rhinoceros* was described by Haitlinger (1989) from Kalimantan. Studies were also carried out on the mites associated with the other members of genus *Oryctes* which were recognized as destructive pests of various palm species. The same author also reported two new species of Canestriniid mites viz *Athogavia tanzanica* and *A. gamana* associated with *O. monoceros* from Tanzania, *A. scagana* associated with an undetermined species of *Oryctes* from Kalimantan. In India, the study on acarine associate of *R. ferrugineus* was found restricted to Tamilnadu was reported by Peter (1989). The above study revealed the presence of three species of mites associated with *R. ferrugineus* of which *Hypoaspis* was more abundant. The occurrence of two distinct morphs of females was observed in the mesostigmatid mite, *Antennoseius janus* by Lindquist and Walter (1989) and they reported that one of the morph was a

phase morph meant for dispersal via insects, which they called as 'phoretomorph' while the other female was found as free living soil predator. Lindquist and Wu (1991) provided a review on the *Mucroseius* mites associated with sawyer beetles belonging to the genera *Monochamus* and *Mecynippus*.

Phoresy was found favoured by some traits to increase the frequency of successful dispersal, and among mites, the dispersal was found achieved by three different types of morphological variants such as unspecialised homeomorphs, specialised homeomorphs and facultative heteromorphs as pointed out by Houck and O'Connor (1991). The authors further mentioned that the unspecialised homeomorphs were morphologically more or less similar with all other stages and got dispersed by grasping the host with their chelicerae or pretarsal claws; the specialised homoemorphs possessed somewhat developed structures like appendicular suckers or corporeal for dispersal. The facultative heteromorphs were specialised developmental stages exclusively evolved for phoresy and they were designated as hypopus in Astigmata. Phoresy was found well established in the order Astigmata so that the definition of phoresy given by Farish and Axtell (1971) could not be applied in its strict sense here. This was based on the finding that the relatively quiescent stages of Astigmata would have to wait for even months to find a suitable host, thereby contradicting the 'active seeking of the host' as mentioned in the definition by Farish and Axtell.

The association of parasitic mites with the insect order Lepidoptera had a long history, with its evidence dating back to the Dominican amber as mentioned by Poinar *et al.* (1991). The small body size of mites would make it difficult to attack the larval and adult stages of insects but insects could serve as important hosts for parasitism and phoresy as stated by Athias-Binche (1991). The Lepidopteran fossils recovered in the Dominican amber were those of two families, Gracillariidae and Tineidae with which two species of ectoparasitic mites of the family Erythraidae were found attached. Athias-Binche (1993 b) pointed out that in Mesostigmata, the phoretic stage could be either the deutonymph of either sexes or the female which might be heteromorphic. Takaku *et al.* (1994) reported 19 species of mesostigmatid mites phoretic on different species of dung beetles in Northern Japan. Studies made by Masan (1994) enabled to record 25 species of phoretic mesostigmatid mites from Slovakia. Zhang (1995) described a new species viz. *Eickwortius termes* of the family Otopheidomenidae

associated with the termite, *Macrotermes michaelsoni* from Kenya. Studies made by Knulle (1995) revealed that astigmatid mites exhibited both polyphenism and polymorphism in order to promote life cycle responsiveness to fluctuations in the environment. Polyphenism could be designated as a phenomenon in which a single genotype could express different phenotypic characteristics in response to varying environment whereas polymorphism denoted the involvement of different genotypes in the expression of different phenotypes. Since many astigmatid mites were found to colonise highly fluctuating and unstable environments, it was assumed that polyphenism would play a significant role in determining their survival value.

Members of Mesostigmata were reported to be the constant associates of cerambycid beetles and Haitlinger (1995) recorded the association of canestriniid mites with the beetle genus *Batocera* from Brazil along with description of a new species viz. *C. phoebinae* collected from *B. albofasciata*. The presence of 12 species of phoretic mites on spruce bark beetle was recorded by Moser *et al.* (1997). It was observed that 77% of the collected beetles were loaded with phoretic mites and the presence of hyperphoretic fungi on the mite phoronts was also recorded. Eraky (1998) reported four species of mites viz. *A. lamiai*, *Forcellinia egyptiaca*, *Mahunkaglyphus solimani* and *Caloglyphus zaheri* as phoretic on *Psammotermes hypostoma*. The same author (1999a) further reported species such as *A. longsetoses* and *Calvolia solimani*, *Mahunkallinia serratus*, *Froneipia negmi* phoretic on *Amitermes desertorum*. The phoretic association of acarid mites such as *Acarus solimani*, *Acotyledon ahmadi*, *A. termesi*, *Caloglyphus ornatus*, *C. subterraneousi* and *Cosmoglyphus barbisetus* on various unidentified species of termites was reported by the above author (1999b; 2000 a; 2003) and Fakeer *et al.* (2014). Ramaraju and Mohanasundaram (2001) described three new species of mites belonging to the family Chaetodactylidae on carpenter bees collected from Tamil Nadu, South India. Biodiversity studies of insect associated mites of Western Ghats were carried out by Ramaraju (2009).

Different species of *Macrocheles* were observed to show phoretic association with coprophilous arthropods to colonise new substrates and Niogret *et al.* (2010) differentiated specialist and generalist categories among the macrochelid mites phoretic on dung beetles. The authors observed that the specialist mites always stayed on the body of their hosts and lived in the nests of the beetles while the opportunists or generalists lived inside the dung pats and screened on the dung quality. Anitha

(2000) reported two undetermined species of *Uropoda* phoretic on the banana weevil, *O. longicollis*. O'Connor (2001) reviewed the various genera of mites under the family Acaridae exhibiting phoretic association with termites such as *Australhypopus*, *Machadoglyphus*, *Mahunkallinia*, *Mahunkaglyphus*, *Cosmoglyphus*, *Sancassania*, *Schweibea* and one unnamed genus. Whitlock (2001) mentioned that dispersal could ensure genetic exchange between populations and determined the distribution of species.

The activity of the dung beetles and the number of mites on the dung pads were found directly related to each other as revealed through the studies of Glida and Bertrand (2002) and they observed that a species of dung beetle genus, *Aphodius* which remained active during the whole year had an important role in the establishment of the population of *Macrocheles* during the extreme cold seasons. Myles (2002) made an account on the Acariformes and Parasitiformes mites associated with laboratory cultures of *Reticulitermes flavipes*. The Acariformes members reported were *Acarus* sp., *A. farris* and *Caloglyphus* sp. of the family Acaridae whereas the Parasitiformes were represented by *Macrocheles muscaedomesticae*, *Parasitus americanus* and *Proctolaelaps hypadari*. The author also made some reflections on the association between mites and termites and reported three species of acarid mites phoretic on the head capsule of termites. Lombardero *et al.* (2003) observed a series of complex ecological interactions between the host beetle, *D. frontalis* and its ectosymbiont/phoront where the phoretic mite, *Tarsonemus* sp. was found to close a loop of interactions like commensalism (between mites and beetles), mutualism (between mites and its hyperphoretic fungi (*Ophiostoma minoris*), competition (between *O. minoris* and mycangial fungi). This happened due to the competition between the hyperphoretic fungi of the mite, *O. minoris* and the mycangial fungi that appeared critical for the beetle nutrition. This loop of interactions showed the significance of the phoretic mite in ecological interactions. Knulle (2003) made an investigation on polyphenism exhibited by two species of acarid mites viz. *Glycyphagus ornatus* and *G. privatus*, which showed two morphs of hypopus, induced by genetic as well as environmental factors. Moraza (2004) observed the phoretic habit of the small sized predatory mites of the family Rhodacaridae on termites. Bajerlein and Bloszyk (2004) conducted studies on a phoretic species of uropodid mite, *Uropoda orbicularis* associated with dung beetles. The authors recorded that the

mites showed preference to specific body parts of their beetle hosts such as subelytra and third pair of legs where they were found frequently distributed. Another important group of mites associated with dung beetles included the Heterostigmata. Khaustov (2005) described three new species belonging to the family Pygmephoridae which were found phoretic on the dung beetle, *Geotrupes stercorarius*. Halliday (2006) recovered phoretic mites belonging to three families viz. Laelaptonyssidae, Teranyssidae and Uronyssidae from the Australian species of termites like *Coptotermes lacteus*, *Mastotermes darwiniensis*, *Nasutitermes graveolus* and *N. exitiosus*. The species of mites recovered included *Laelaptonyssus laticolus*, *Teranyssus howardensis*, *Uronyssus milleri* and *U. watsoni* and the author suspected the above species as parasites of termites. Hartini (2006) reported 10 species of mites belonging to the genus *Macrocheles* associated with dung beetles from Papua, Indonesia. Two species of adult females of *Antennoseius*, viz. *A. perseus* and *A. pyrophilus* were recognized as phoretomorphs on pyrophilous carabids as mentioned by Beaulieu *et al.* (2008) and they experimentally demonstrated that dimorphic adult females were widespread in the genus. Though the insect-mite correlation had a long history to boast, there was a deficiency in the literature about these correlations as mentioned by Haitlinger (2008). The association of 14 species of mites belonging to the family Macrochelidae was reported by Hartini *et al.* (2009) on the dung beetles collected from Indonesia. They also mentioned that the association was seen in both the orders like Trombidiformes and Sarcoptiformes while in Parasitiformes, the association was found evolved only in the order Mesostigmata.

Krantz (2009) reported that phoresy in Astigmata was achieved by a morphologically specialised stage called 'hypopus' which was characterised by well developed anal suckers to hold on to the arthropod cuticle and degenerated mouthparts. The author also reported the phenomenon of phoretomorphy among members of the Heterostigmatine superfamilies like Pygmephorodea and Scutacarodea. Camerik (2009) classified phoresy in to three types such as occasional or accidental, facultative and obligate. Accidental phoresy was resulted from accidental meeting of a free living mite with a carrier for a ride. Phoresy was termed facultative when it occurred in unpredictable transient habitats while obligate phoresy occurred in predictable stable environments. Porcelli *et al.* (2009) observed the presence of hyperphoretic fungi on the mites, *C. almerodai* and *Uroobovella marginata* which were phoretic on the red

palm weevil. The authors emphasised the need for further investigation on the role of phoretic mites in dispersing conidial spores, which might be harmful to the palm. It was assumed that the hyperphoretic fungi might be detrimental to the host tree of the carrier beetle or would have additive effects on the efficiency of the carrier beetle to spread fungal diseases as observed by Moser *et al.* (2010). According to the authors, the high efficiency of the bark beetle, *Scolytus scolytus* in spreading the Dutch elm disease might be partially attributable to the phoretic mites carried by it.

Bahrami *et al.* (2011) conducted studies on the biodiversity of phoretic mites associated with different species of dung beetles, the results of which revealed the presence of 37 species of mesostigmatid mites. The greatest diversity of phoretic acari was observed on the dung beetle species, *Euonthophagus gibbosus*. Al-Deeb *et al.* (2011) carried out detailed studies on the phoretic associates of *R. ferrugineus* in UAE and identified three species viz. *Uroobovella* sp., *U. orbicularis* and *Curculanoetus* sp. from different body parts of the body of the adult weevil host, with the most preferred body regions being the subelytral surface.

The phoretic habit of Heterostigmatine mites on Cerambycidae was reported to be quite uncommon. Mori *et al.* (2011) observed variations in the number of phoretic mites carried by the pine beetles depending upon changes in the season. Rahiminejad (2011) reported two new species of mites belonging to the genus *Elattoma* (Heterostigmata: Pygmephoridae), *E. cerambycidum* and *E. abeskoun* phoretic on *Morimus verecundus*, pest of oak trees, and which formed the first report on the association of a heterostigmatid mite with Cerambycidae. The oldest record of phoresy was claimed to be recovered from the Baltic amber preserved fossil, which showed the association of *Uroobovella* with the Coleopteran, longhorn beetle *Nothorhina granulicollis*. The fossil record was estimated to be of Eocene period (44-49 Mya) and the association of phoresy was confirmed since the phoretic deutonymphs got attached to the beetle via its anal pedicel, as reported by Dunlop *et al.* (2013). Pfammatter *et al.* (2013) observed that the number of phoretic mites on the bark beetle species, *I. pini* got changed according to the differences in seasons. The authors observed that the beetles which were collected late in the season had an increased mite load and harboured more number of species than the beetles which were collected early in the season.

Phoretic association between the uropodid mite species, *Trichouropoda shcherbakae* and its beetle host of the cerambycid genus *Tetropium*, a pest of forest trees was reported by Bloszyk *et al.* (2013). Taha *et al.* (2014) collected 13 species of mites representing the parasitic and predatory categories associated with *R. ferrugineus* from Egypt. The authors observed that the members of the family Tachyuropodidae formed the most abundant group among the eight families present, and other families recovered were Uropodidae, Ascidae, Macrochelidae, Digamasellidae, Trematuridae, Laelapidae and Sejidae. Majority of the mites associated with this species were identified as phoronts on the weevil. A new species of Uropodid mite, *Nenteria extremica* was described from Italy by Kontschan *et al.* (2014). Metwally *et al.* (2014) collected and identified 38 species of mites under 29 genera, 16 families, 4 suborders and 2 orders from coleopteran insects of Egypt. Of these, 19 species belonging to 12 genera and 6 families were included under suborder Gamasida, 12 species under 10 genera and 6 families were categorized under suborder Actinedida, 6 species under 6 genera and 3 families were included under suborder Acaridida and one species belonging to a single genus and family represented the suborder Oribatida. Dilipkumar *et al.* (2015) listed 25 species of mites belonging to 21 genera and 18 families recorded from the beetle until the date. Accordingly, the phoretic mites on *R. ferrugineus* were reported from 16 countries, most of the reports were made from Egypt. The study also reported five species of mites; *Centrouropoda almedorai*, *Macrocheles mammifer*, *M. oigru*, *Uroobovella assamomarginata* and *U. javae* phoretic on the weevil which formed new host record from Malaysia. The authors could observe discrepancy in the number of phoretic mites carried by the male and female individuals of the weevils. It was observed that the male weevils carried significantly higher number of phoretic mites than the females, subelytral surface was the most preferred region for the phoretic mites and Uropodidae formed the important as well as abundant family comprising the constant mite associates of *R. ferrugineus*.

Robin *et al.* (2016) pointed out that insect-mite association occurred 320 mya, as revealed through paleontological evidence on the association of a fossilised oribatid mite and an extant relative of grasshopper. The phoretic habit of bulb mites, *Rhizoglyphus echinopus* commonly found associated with ornamental plants, bulbs and tubers was reported by Silva *et al.* (2016) on the head of subterranean termite, belonging to the genus *Coptotermes*. Zach *et al.* (2016) observed that different species

of phoretic mites had different bark beetle dispersants and speculated that niche-partitioning among different species of bark beetles, was reflected by a change in the composition of phoretic mites. Records of heterostigmatic mites phoretic on termites were found limited to some families like Scutacaridae, Pygmephoridae, Microdispidae, and Dolichocybidae. Roy *et al.* (2016) provided data on the insect associated mites of West Bengal. Phoretic habit of a new species of Scutacaridae viz. *Coronipes sperati* was observed by Khaustov *et al.* (2016) on the termite species, *Reticulitermes sperati*. The same authors further (2017) described a new genus of the family Scutacaridae, viz. *Gerdalbertia* associated with another termite species, *Trinervitermes trinervoides*. The genus *Hypoaspis* was recorded to be a constant associate of *Oryctes* and Gima (2017) reported an unidentified species of *Hypoaspis* phoretic on *O. nasicornis* from the Dolj County.

The association of mites belonging to families of Heterostigmata such as Dolichocybidae, Neopygmephoridae and Pygmephoridae was recorded in scarabaeid dung beetles by Sobhi *et al.* (2017) from Iran. Moraza and Lindquist (2018) described a new species group and a new species of Blattisociidae viz. *Lasioseius cassidini* associated with hispine leaf beetles, but the types of association between the mites and weevils were not clearly demarcated.

Baumann (2018) observed that heterostigmatic mites belonging to the family Scutacaridae depended on dung beetles for transport. Khaustov and Frolov (2018a) described a new species under the genus *Formicomotes*, viz. *F. brasiliensis* phoretic on the termite, *Nasutitermes* for the first time from the Neotropical region. A new species of *Scutacarus* viz. *N. termitophilus* was described by Khaustov *et al.* (2018 a) which was found associated with the nests of the above termite species from South Africa. The termite species, *T. trinervoides* was also reported to carry members of the acarine family, Microdispidae, as revealed through the studies of Khaustov *et al.* (2018 b), and the authors described two new species viz. *Parapunicodoxa striata* and *Punicodoxa lineata* from South Africa, which formed the first record of the family from the country. A new species of Scutacaridae viz. *Imparipes clementis* was described by Baumann and Ferragut (2019) from Spain, and the species was found phoretic on *Reticulitermes banyulensis*. Vissa *et al.* (2019) observed significant variation in the relative abundance of mite species with respect to variations in the

species of bark beetles, in Portugal which indicated the importance of phoretic hosts in determining the species composition of mites.

Trach *et al.* (2019) provided evidence on the constant phoresy of mesostigmatid mites on cerambycid beetles by reporting a phoretic species of mesostigmatid soil mite, *Mucroseius insolitus* on the sawyer beetle, *Monochamus galloprovincialis*. Bhadran and Ramani (2019) reported two species of phoretic mites viz., *Histiostoma* sp. and *Macrocheles muscadomesticae* on the banana weevil, *O. longicollis* and the authors made further observations on the most preferred body regions of the phoretic mites and which revealed the sub-elytra of the weevil host as the most preferred site for attachment. Recent report on phoretic mite associates of the weevil from southern Spain was made by Abolafia and Ruiz-Cuenca (2020), by recording the phoretic habit of only one phoretic species viz. *Trichouropoda* sp. Studies made by Bubrig and Fierst (2021) disclosed that the phoronts increased the chance for their dispersal in four ways such as preparing for dispersal, lodging on the vector, surviving during travel and dislodging from the carrier, on reaching a suitable habitat.

Phoresy- a road to parasitism

Mitchell (1967) considered phoresy as a pre-adaptation to parasitism, based on his observations in the larvae of hydracarid mites, which would lead a parasitic life on aquatic insects while the adults appeared to be free living predators. The larva though originally meant for dispersal, developed parasitism as a secondary behaviour, and this evolutionary transition of a free-living organism to a parasitic mode of life which include predator-prey interaction, co-habitation and preadaptation phoresy, more specifically, from obligate to seasonal phoresy could be explained through many hypotheses. Often, obligate stenoxenous species with a very narrow range of host specificity would get forced to synchronise with that of the host life cycle which would finally lead to paraphagy, a condition of feeding on the host secretion rather than the host itself. Paraphagy was found exhibited by the phoretic deutonymphs of *Poecilochirus carabi* feeding on the oral secretion of their carrier silphid beetle as revealed through the studies of Springett (1968). The type of association called 'necromeny' further warranted the transition of a phoretic mode of life to parasitism and Samsinak (1970) pointed out necromenic association in several astigmatid groups. Also, the transition of phoretic nidicolous acarid lineages to parasitism was known to

take place in a very small evolutionary time gap. Finally, when parasitism evolved, the facultative hypopal stage disappeared and in the absence of the hypopus, some of the bird parasitic mites of the family Epidermoptidae ensured transportation by enjoying dispersal on some dipteran parasitic flies infesting birds as explained by Hill *et al.* (1967); Bottiker and Cerny (1974). The former laid eggs on the flies and which got transported to the host bird.

The notion that the phoronts could make an impact on the carrier host was established by on detection of symptoms developed by the carrier, such as impeding its ability to flight take off, affecting its longevity etc. Kinn and Witcosky (1978) observed variation in the height of pine beetle attack with change in density of phoretic mites attached to them thereby affecting mobility of host beetles. The phoretic hypopi of Histiostomatidae were found to alter the behaviour as well as flight ability of its dipteran host, *Musca domestica* as recorded by Elzinga and Broce (1988). Necromeny was designated by Schulte (1989) as a kind of association “where an organism could attach on the carrier organism when it was alive and would wait for the death of the carrier organism to complete its development on the carcass of the carrier.” The occurrence of a significant number of phoretic loads on the carrier was found to affect the longevity of the host. Athias-Binche and Morand (1993 a) referred phoresy as a special form of parasitism in which the phoront did not directly feed on the host. They emphasized that the phoretic species could induce physical constraints that might force the carrier either to reduce its activity or to spend more energy for movement. This notion was further warranted by the experiments of Athias-Binche (1994) with *Hemisarcoptes cooremani* and its host beetle, *Chilocorus cacti*. The deutonymphs of *H. cooremani* in its deutonymphal stage had no functional mouthparts, chelicerae and a functional gut but the authors could isolate tritiated water from the hindgut of the deutonymph obtained from the host beetle. This, they thought was obtained from the carrier beetle during the transport. They also found that the beetle’s haemolymph was a prerequisite for further development of the phoretomorph, i.e, in the absence of the weevil, the deutonymphs died without undergoing further molt. This established the commencement of a parasitic mode of life.

Kotiaho and Simmons (2001) observed that when the phoretic load on the dimorphic dung beetle, *Onthophagus binodis* was experimentally manipulated, the longevity of the male beetles got reduced significantly. The association of the astigmatid mite,

Histiostoma polypore with its carrier earwig, *Forficula auricularia* was identified as necromeny by Wirth (2009) and the author observed that the phoretic deutonymphs of *H. polypore* detached from the carrier female earwig to develop on the dead earwig nymphs. A reduction in the flight take off ability of *Rhizopertha dominica* was observed when the load of phoretic mite, *Acarophenax lacunatus* got increased, thereby confirming that high load of phoretic mite would reduce the flight ability of the carrier host as reported by Rocha *et al.*(2009). Al-Deeb *et al.* (2011) speculated that the phoretic mites, *Uropoda orbicularis*, *Uroobovella* and *Curculanoetus* could reduce the efficiency of flight and foraging activities of red palm weevil and also would make them susceptible to predation.

Mazza *et al.* (2011) on experimenting with the carrier host red palm weevil, *R. ferrugineus* and its phoront, *Centrouropoda almedorai* observed that the phoretic load of mites reduced the longevity of the weevil. The association of necromeny was experimentally proved in the deutonymphs of *Sancassania* sp. phoretic on the adults and larvae of *Oryctes agamemnon arabicus*. The deutonymphs of *Sancassania* were found to resume development on the decapitated carcass of the weevil which implied a necromenic relationship along with phoresy as recorded by Al-Deeb *et al.*(2012). An alteration in the behaviour of the carrier was also noted by Houck *et al.* (2013) based on their finding that the plum curculio, *Conotrachelus nenuphar* harbouring more number of phoretic *Histiostoma* deutonymphs showed little response to the normally attractive synthetic odours. The association called necromeny was found more prominent among the nematodes in nematode- invertebrate associations as pointed out by Kiontke and Sudhaus (2006). The evolutionary ecology could answer the dilemma of phoresy to parasitism transition in another way based on the viewpoint that the transition towards parasitism was not a one-step process, rather it evolved via some intermediate transition stages like endophoresy, necromeny, facultative parasitism and obligate parasitism as explained by Crook (2014). The ‘pre-adaptation’ strategy was also found proficient in explaining the transition of phoresy to parasitism as pointed out by Luong and Mathot (2019). It was hypothesised that the development of an intermediate association like phoresy favoured suites of adaptation that eventually could accommodate the phoretic associate in a parasitic mode of life.

The phoretic mites exhibiting necromenic association was also recorded in *Odoiporus longicollis* by Bhadran and Ramani (2019) by observing that the phoretic

deutonymphs of *Histiostoma* developed on the decapitated carcass of the weevil. Based on their finding that some of deutonymphs of *Histiostoma* got dislodged from the carcass of the weevil even in the presence of a suitable substrate, the authors designated the association as facultative necromeny. Bubrig and Fierst (2021) attempted to expound on the 'Dauer hypothesis' which described the transition of phoresy to parasitism in nematodes. According to Dauer hypothesis, the road to parasitism began early as non- associating organisms. The ecological condition prevailing at that time could decide whether the lineage would get evolved towards parasitism. The second step after non-association was phoresy followed by necromeny and finally to parasitic mode of association.

Parasitism

The pioneer work of Riley (1878) and the subsequent work of Howard (1918) enabled to provide much valuable data on the biology, life cycle, seasonal history and the economic importance of the grass hopper mite, viz. *Eutrombidium trigonum*, which served as an important biological check in controlling the populations of grass hoppers. The mite was reported to offer dual levels of grass hopper control as its larvae could successfully parasitize the adult grass hoppers while its nymphal and adult stages preyed upon the grass hopper eggs. Later on various authors like Howard (1918), Wehrle and Welch (1925), Lawrence (1940), and Radford (1946) provided data on the mites belonging to families like Trombidiidae, Erythraeidae, Tarsonemidae, and Tyroglyphidae attacking orthopteran insects like the grass hoppers and locusts. Newstead and Duvall (1918) provided a description of the mite, *Acarophenax tribolii*, which was recognized as an important egg parasite of the stored product insect pest, *Tribolium confusum*. The impact of parasitic mites in honey bees was well studied by many and it was White (1921) who secured much information on the mechanical effects of tracheal obstruction in honey bees induced by the infection of the tracheal parasitic mite, *Acarapis woodi* and he also provided experimental evidence for the incidence of Isle of White disease in honey bees. Severin (1944) provided an elaborate account on the taxonomy, distribution, life history as well as morphological aspects of the various life instars of the grass hopper mite, *E. trigonum*. Majority of the findings of acarine associations with moth were made by Treat (1954) who described a novel species of gamasid mite, *Myrmonyssus phalaenodectes* associated with the tympanic membrane of *Pseudaletia unipuncta*.

The mite was recorded as parasitic and even punctured the tympanic membrane of its host. The genus *Blattisocius* was reported to be associated with noctuid moths. The earliest report of parasitic impact of the members of *Blattisocius* was made by Evans (1958) in which, *B. dentriticus* was reported to be parasitic on noctuid moths. Lindquist and Bedard (1961) came up with their observation on species of *Tarsonemoides* which parasitized the eggs of bark beetles. The larvae of mites coming under the genera like *Balaustium* and *Bochartia* of the family Erythraeidae and *Allothrombium* of the family Trombidiidae were reported to be parasitic upon the larvae of woolly aphids as mentioned by Evans *et al.*, (1961). Corbet (1963) reported that the parasitic larvae of mites would make the female mosquitoes nulliparaous and therefore he used the living parasitic mites on mosquitoes as reliable indicators to denote the nulliparous condition of hosts. Treat (1966) reported and described a novel species of *Blattisocius*, *B. patagiorum* which was found parasitic on noctuid moths.

Hinckley (1967) reported a species of laelapid mite, *Coleolaelaps* sp. ectoparasitic on the adults and grubs of *Oryctes rhinoceros* whereas they were found to feed on the inner content of eggs. Regenfuss (1968) reported the incidence of parasitic podapolipid mites on 24 species of grasshoppers out of the 78 species examined. In the study, he reported the presence of 30 species of podapolipidae out of which 24 were new. Most of the species reported were monospecific. Prasad (1968) reported three species of mites associated with noctuid moths; *Neocypholaelaps linguisti* from the family Ameroseiidae, *Proctolaelaps lobatus* and *B. keegani* from the family Ascidae. *B. tarsalis* which was recorded as larval predator of stored product insects earlier was reported found phoretic on the noctuid, *Epizeuxis aemula* as revealed through the studies of Treat (1969). Incidence of a parasitic mite, *Coleolaelaps procerus* on *O. rhinoceros* was reported by Manjunath *et al.* (1969). Lindquist (1969 b) made a review on the tarsonemid egg parasites of pine bark beetles and found that most of the recovered species were monospecific and those which were not monospecific showed a preference to get attached to the body of closely related species of host insects. The same author (1969 c) reported four species of parasitic mites of the genus, *Tarsonemus* in association with bark beetles in conifers, all of which were found to colonise subcortical region of the host. Subsequently, the author (1970) observed that larger species of insects in the forest floor would serve as hosts to a wide variety of mites including external and internal parasites, commensals and

phoretic commensals. Tiwari (1971) recorded parasitic association of a species of *Uropoda* with the weevil host, *O. longicollis*.

Species of *Hypoaspis* and *Coleolaelaps* seen in association with *O. rhinoceros* were recommended for the biological control of the above host in Fiji and Pacific area by authors like Rao (1971), Swan (1974) and Lomer (1985). A new species of parasitic mite viz. *Otophiedomenis zalelestes* found on the tympanic membrane of the moth, *Zale lunata* was described by Treat (1975). The author observed that the mite fed on other body parts of the insect and did not make any harmful impact on the tympanic membrane of the host.

Larval stages of mites belonging to acarine families Arrenuridae, Thyasidae, Anysidae, and Hydryphantidae were reported as important ectoparasites, enjoying a wide range of insect hosts in freshwater habitats as revealed through the studies of Mullen (1975) and Smith (1983). While investigating the natural enemies of the chinese grasshopper, *Oxya chinensis*, Mandras and Gapasin (1979) observed an undetermined species of ectoparasitic mite clinging to the body of the grass hopper. According to Lindquist (1983), Heterostigmatic mites like *Acarophenax*, *Pyemotes* and *Iponemus* were similar to insect parasitoids in sharing many features like ensuring destruction of host, requiring a single host for development of one or more progeny, parasitic mode of feeding habit exhibited only by the adult female stage and the latter serving as the dispersal stage, primarily attacking the host during its immature stage like the egg, larva or often the pupa, feeding mode greatly resembling predation rather than parasitism, in relation to the host population parameters. Hochmuth *et al.* (1987) traced the impact of the ectoparasitic species of podapolipid mite, *Coccipolipus epilachnae* on feeding, fecundity and longevity of soybean-fed adult Mexican bean beetles at different temperatures. A novel species of Erythraeidae, viz. *Leptus oxyae* was described by Vishnupriya and Mohanasundaram (1988) to be ectoparasitic on *Oxya nitidula* in Tamil Nadu. Smith (1988) reported that some members of Parasitengonina exhibited a biphasic life cycle, serving roles both as predator and parasite. Their life cycles were found to comprise different developmental stages like egg, pre-larva, larva, three nymphal stages and adult stages in which the adults exhibited predation upon insects. Eickwort (1990) reported the cleptoparasitic habit of a mesostigmatid mite, *Sphaerolaelaps holothyroides* on British *Lasius* ants nesting in soil. The mite was found to derive its food by intercepting trophallaxis by its host.

Phoretic and parasitic mites were found harboured by different species of leaf beetles and Peterson *et al.* (1992) reported two ectoparasitic larvae of Trombidiidae viz. *Trombidium hyperi* and *T. newelli*, infesting the bean leaf beetle, *Ceratomatrifurcata*. This finding formed the first report on the parasitic genus on the bean leaf beetle. Santiago-Blay and Fain (1994) listed some acarine families which were found commonly associated with Chrysomelidae, such as the astigmatid families, Heterocoptidae, Canestriniidae and Hemisarcoptidae and the prostigmatid family Podapolipidae. Of these, members of Heterocoptidae and Canestriniidae were found usually fungivorous and sometimes feeding on the exudates of abdomen and hence sharing a commensalistic relationship with the beetle hosts, while the families like Podapolipidae and Hemisarcoptidae were found purely parasitic. Infestation by the parasitic mites of the genus *Locustacarus* viz. *L. buchneri* and *L. trachealis* in the eusocial bees of the genus *Bombus* was reported by Husband and Husband (1996). Ectoparasitic species of Parasitengonina were observed to feed on the haemolymph or tissue fluid of the host, typically draining out nutrients from the hosts, as recorded by Reinhardt (1996). Houck *et al.* (1998) observed that the deutonymphal parasitoid mites associated with queen bumble bees overwintered with the bees and were even transported to their new nests. Ramaraju and Mohanasundaram (1996, 1999) described new species of parasitic mites belonging to genera like *Podapolipus*, *Podapolipoides* and *Tarsopolipus* infesting orthopterans collected from Tamil Nadu, India. Polak and Starmer (1998) experimentally demonstrated that *Drosophila nigrospiracula* parasitized by *Macrocheles subbadius* increased the mating frequency thereby creating a greater reproductive success in the parasitized population. Studies made by Schmid-Hempel (1998) revealed that some of the mite species coming under the family Macrochelidae specifically got attached to the membranous areas of host bodies so as to suck the host haemolymph. Husband and O'Connor's (1999) report on the ectoparasitic mites like *Rhynchopolipus swiftae* on *R. ferrugineus* and *R. brachycephalus* on *R. phoenicis* warranted further investigation to prove their potential use in the biological control of the beetle pest. Rolff *et al.* (2000) pointed out that the pre-larval stage of Parasitengonina might establish initial attachment to the host as a phoretic partner and upon completion of the ectoparasitic larval stage, they would drop off from the host to the water bodies, leaving scars of parasitism on the host body. The incidence of the ectoparasitic mite, *Trombidium hyperi* on the bean leaf beetle was recorded by Danielson *et al.* (2000) and the author also noted that the

percentage of mite infestation on beetles got increased from 4% to 40% within one year. Most of the mites associated with leaf beetles were found to be specialists rather than generalists. It was observed that parasitic mites would induce several behavioural alterations in their hosts like sexual selection, choice of oviposition sites, respiration, flight, dispersal etc. As a step to escape from parasitism, the host often showed an increased tendency to disperse, as observed by Boulinier *et al.* (2001).

The feeding spectrum of parasitic mites would help to determine their categorization as ‘generalist’ or ‘specialist’, and the generalists would normally infest a wide range of hosts while specialist would stick on to a single host or group of hosts, as pointed out by Combes (2001). González *et al.* (2004) conducted studies on the biology and behavior of the uropodid mite, *Macrodonychus sellnicki* which was recognized as an ectoparasite on the crazy ant, *Paratrechina fulva*. Breton *et al.* (2006) reported an unidentified uropodid mite species parasitic on the ant species, *Pheidole megacephala* in Japan. Hatcher *et al.* (2006) discussed the importance of parasites in building up a community structure by promoting species exclusion or co-existence. Okabe and Makino (2008) found that truly parasitic mites like *Ensliniella parasitica* exhibited low plasticity in life cycle and its life cycle halted upon the death of its host wasp, *Allodynerus delphinalis*.

Krantz (2009) pointed out that parasitic mites would damage their hosts by inducing weight loss and anaemia by intensive feeding, eliciting allergic responses and sometimes reducing the reproductive potential of the host. Abdullah (2009) provided evidence to prove the potential of the podapolipid mite, *R. rhynchophori* as an effective biocontrol agent of *R. ferrugineus* and results of his study gave an insight in using the acarine natural enemies in the biocontrol of the weevil. Studies made by Hassell *et al.* (2010) showed that parasitic mites could also attach to unparasitised adults during mating. Further investigations made by the authors revealed the sexual preference and body site preference of parasitic mites, indicating that parasitic mites preferred to get attached to the thorax when compared to other body parts.

Sarangi *et al.* (2010) conducted surveys on the acarine associates of Lepidopteran pests distributed in India and reported species like *Entomoseius* sp. from *Hypolimnas* sp., *Otopheidominas* sp. and *Hemipteroseius* sp. from *Danaus chrysippus*, *Proctolaelaps* sp. from *D. limniace*, *Pachylaelaps* sp. from *Elymnias hypermnestre*,

Ornithonyssus sp. and *Alliphis* sp. from an undetermined Lepidopteran species. They also reported five species of mites belonging to three families like Saproglyphidae (*Suidasia nesbitti*), Podapolipidae (*Podapolipus* sp., *Podapolipoides* sp., *Locustacarus* sp.) and Johnstonianidae (Unidentified sp.) from parasitic on *O. nitidula*. The same authors (2012) described two new species of ectoparasitic mites of the genera *Podapolipus* and *Podapolipoides* infesting *Oxya* sp. from West Bengal, India. A new species of *Podapolipoides* viz. *P. yucatanensis* was described by Husband and Wohltmann (2011) from an acridid host, *Schistocerca piceifrons*. Sultana *et al.* (2012) studied the effects of infestation by the macro-parasitic mite, *Eutrombidium trigonum* on the life history parameters of three species of *Hieroglyphus* viz. *Hieroglyphus perpolita*, *Hieroglyphus oryzivorous* and *Hieroglyphus nigrореpletus* from Sindh, Pakistan. The authors reported that mite parasitism induced significant reduction in the rate of egg production as well survival of the females of all the species. Sarangi (2014) reported two species of parasitic mites associated with *O. rhinoceros* from India viz. *Hypoaspis* sp. and *Suidasia nesbitti*. Parasites would play a pivotal role in determining the intra-guild predation rates by altering factors like appetite and vulnerability to predation as noted by Hatcher *et al.* (2013). Biological aspects of a parasitic mite, *Aegypticus rhynchophorus* were studied by Taha *et al.* (2014) by rearing the species on a diet comprised of the pupae of the red palm weevil. The dilution effect in parasitism which occurred during increased host diversity was reviewed by Worthen and Turner (2015).

Parasites were rated as the dark-matter in the dynamics of ecology by Worthen and Turner (2015). Water mites which were parasitic on mosquitoes were found to exhibit a specialist parasitic behaviour by exhibiting a special preference to a particular species, *Culex* than the remaining species under study as mentioned by Atwa *et al.* (2017). The parasitic mite, *Macrocheles subbadius* was found to influence the ovipositing behaviour of *D. nigrospiracula* as reported by Mierzejewski *et al.* (2019) and the flies were found to avoid oviposition at the sites with parasitic mites as long as the environmental conditions were identical. Parasites would affect the evolutionary pathway either by promoting or reducing the host diversity. According to Benoit *et al.* (2020), parasites should be considered as a driving force for the evolution of host resistance, based on the important role of parasitism in determining the host fitness. Katlav *et al.* (2020) reported the presence of three new species of

heterostigmatid mites associated with beetles of eastern Australia, out of which one species, *Eutarsopolipus orpheus* was parasitic on its host insect, *Gnathaphanus melbournensis*. Majidi *et al.* (2022) described a new species of *Podapolipoides* viz. *P. chorthippus* which was found to lead an ectoparasitic mode of life style on *Chorthippus* sp., belonging to family Acrididae if the order, Orthoptera from Southern Iran.

Predation

Predation on life stages of insects by mites, especially members of different families of Mesostigmata, Prostigmata and Astigmata was recorded much earlier by authors like Walsh (1868), Shimer (1868 a), Riley (1873), Lignieres (1893), and Ewing (1912) who delineated incidence of mites attacking the eggs and adults of scale insects, thereby playing vital roles in the natural control of scale insect pests. Baker and Wharton (1952 a) reported that the acarid mite, *Thyreophagus entomophagus* associated with scale insects fed on dead insects and cast skin. This finding eliminated the misconception that the mites preyed on eggs and nymphal stages of insects. The same authors recorded *Hemisarcoptes malus* as an important predator of scale insects like *Lepidosaphes ulmi* in France, Germany and eastern Canada, *L. beckii* in California, *Parlatoria oleae* in California, *Aspidiotus lontana* in California, and *Aonidiella periciosa* in France. Walter and Campbell (1955) observed predatory mites associated with Douglas-fir beetle from Canada and mentioned that the species could act as biological control agent of the beetle species. The authors also reported the presence of *Calvolia* sp., *Dendrolaelaps quadrisetus*, *Lasioseius* sp., *Parasitus* sp. and *Uropoda* sp., the presence of which was found to reduce the life span of 22-33% larvae. Barker (1967) reported that the immature and adult stages of *Blattisocius* sp. fed on eggs of grain beetles like *Tribolium confusum*, *T. castaneum*, *Trygoderma* sp. and *Oryzaephilus surinamensis*. During his investigation on the host specificity of predatory mites, Lindquist (1969 c) found that most of the predaceous mites of the genera *Lasioseius*, *Proctolaelaps* and *Digamasellus* were not very host specific, but were habitat specific. The same author (1970) reported that smaller insects found on the forest floor such as collembolans and ptiliid beetles would serve as prey to large predatory mites belonging to Mesostigmata and Prostigmata. Ibrahim (1971) reported that the predatory mite, *Cheletogenes ornatus* attacked the eggs and crawlers of scale

insects like *P. oleae*, *L. ulmi* and *Ceroplastes floridensis* infesting on different fruit trees. In Florida, the Bdellidae member, *Bdella distincta* was observed to feed on the eggs and crawlers of armoured scale insects as stated by Muma (1975). Gerson and Schneider (1981) conducted life history studies of the predatory mite, *H. coccophagus* which was found to prey upon the armoured scale insects and the California red scale. The most studied group of mesostigmatid predators were included under the family Phytoseiidae as stated by McMurtry (1983). Swirski and Dorzia (1969) studied the feeding habits of the phytoseiid predator, *Typhlodromalus limonicus* and found that it could feed and reproduce on a diet of the hemipteran notorious pest, *Bemisia tabaci*. Nassar (1976) conducted studies on *Cunaxa setirostris* which was identified as an aerial predator of two species of scale insects viz. *Lepidosaphes beckii* and *Saissetia oleae* in Egypt. Zhang and Xin (1989) recorded the trombidid mite, *Allothrombium pulvinum* as an important natural enemy of aphids and several small bodied arthropod pests in China, as its larvae were found ectoparasitic on aphids while its deutonymphs and adults served as predators on aphids, spider mites and also the eggs of lepidopterans. Studies of Ramakers *et al.* (1989) revealed that the phytoseiid mite, *Amblyseius cucumeris* could be effectively used for the biological control of the western flower thrips, *Frankliniella occidentalis*. The predatory potential of five subtropical species of phytoseiid mites viz. *A. hibisci*, *A. degenerans*, *A. limonicus*, *A. scutalis* and *A. tularensis* on thrips was assessed by Van Houten *et al.* (1995) and based on the results of their study, the authors concluded that *A. hibisci* and *A. degenerans* were the most promising candidates for the biocontrol of the western flower thrips. Van Houten (1996) recorded excellent control of western flower thrips by using *Typhlodromalus limonicus*, though there was difficulty in the mass rearing of the species for its commercial use. Ramaraju and Mohanasundaram (1999) described two new species of cheyletid predators viz. *Cheletophyes xylocopae* from *Xylocopa* sp. and *Samsinakia carabae* from a carabid beetle collected from Tamil Nadu, India. Phytoseiid species like *T. swirskii* and *E. scutalis* were reported to suppress the population of *B. tabaci* on cucumber plants as revealed through the studies of Nomikou *et al.*, 2002. Premachandra *et al.* (2003) reported that the combined release of entomopathogenic nematodes and the predatory mite, *Hypoaspis aculeifer* would provide effective control of the soil dwelling stages of western flower thrips. Weithoff *et al.* (2004) tested the efficacy of the combined release of the predatory mites, *A. cucumeris* and *H. aculeifer* in controlling the western flower thrips

and the results of their study showed that the release of *A. cucumeris* provided a comparable effect as that of the combined release of both species of mites. During their investigation to find out the best predatory mites for controlling western flower thrips, Messelink *et al.* (2006) observed that species like *T. limonicus*, *T. swirskii* and *E. ovalis* could serve as good biocontrol agents against thrips. El-Sayed and Ghallab (2007) made a survey on the predatory mites associated with stored grain pests and the results revealed the occurrence of 13 species of predatory mites with the most abundant species being *Blattisocius keegani*, *Cheyletus malaccensis* and *Blattisocius tarsalis*.

Families like Ameroseiidae, Ascidae, Davacaridae, Laelapidae, Macrochelidae, Ologamasidae were reported by Beaulieu and Weeks (2007) to represent some aerial predatory groups inhabiting on plants. The prey suitability of western flower thrips like *F. occidentalis* and *Thrips tabaci* to the predatory mite, *A. swirskii* was tested by Wimmer *et al.* (2008) and the authors reported that the predator preyed upon the first larval instars of both species of thrips. Krantz (2009) made a review on the common families of predatory mites inhabiting the soil ecosystem and aerial parts of plants and encountered mesostigmatic predatory like Parasitidae, Macrochelidae, Digamasellidae, Laelapidae, Ascidae, Zerconidae, Uropodidae, Ologamasidae etc. and the prostigmatid predatory families like Eupodidae, Rhagidiidae, Bdellidae, Labidostomatidae, Stigmaeidae and Cheyletidae in the soil ecosystem. The trombidiform families associated with the foliage of plants included Stigmaeidae, Tydeidae, Cheyletidae, Anystidae and Erythraeidae. The author further noted that the astigmatid aerial feeders were very few, such as Hemisarcoptidae and Winterschmidtidae. *Agistemus exsertus* of the family Sigmaeidae was recognized as the most common generalist predator of phytophagous mites, some scale insects, whiteflies, stored product moths, and pollen grains as mentioned by Saber and Rasmy (2010). Mc Murtry *et al.* (2013) mentioned that the members of phytoseiidae would serve as important predators of other mite groups, thrips and whiteflies. Wu *et al.* (2014) reported that the mesostigmatid mite, *Stratiolaelaps scimitus* caused successful reduction of the population densities of thrips like *T. tabaci* and *F. occidentalis* on cucumber plants, based on greenhouse experiments. A detailed review on the important pest and predatory mites was provided by Fathipour and Maleknia (2016) and they suggested some comprehensive methods to evaluate the efficacy of predators

in terms of their selection for management programs. The authors also discussed the future of biocontrol of mites and marketing of biocontrol agents. According to Tixier (2018), predatory mites should be considered as a key solution for the biological control of pest mites as well as small arthropods. Navarro-Campos *et al.* (2020) proved that the predatory mite species, *Hypoaspis aculeifer* as a promising natural enemy for the control of citrus thrips like *Pezothrips kellyanus* (Bagnall) in the laboratory, greenhouses as well as in the field conditions. Castro-López and Martínez-Osorio (2021) also highlighted the importance of the above species as an excellent biocontrol agent of thrips like *T. tabaci* infesting onion plants in greenhouse experiments. Studies of Yan *et al.* (2022) proved that the predatory mesostigmatid species, *Stratilaelaps scimitus* could provide promising results in controlling sciarid flies infesting Chinese chive plants. Beretta *et al.* (2022) supplemented an elaborative review on the predatory soil mites which could be used as biocontrol agents of above and below ground plant pests.

Chapter 3

Materials and methods

During the present investigation, sampling was carried out randomly from diverse types of ecosystems like agroecosystems, agricultural fields, vegetable gardens, botanical gardens, coconut plantations, banana plantations, kitchen gardens etc. to collect insect pests of agricultural importance. A total of 29 collection localities distributed over four districts of Kerala viz. Thrissur, Palakkad, Kozhikode and Malappuram (Table 1.1, Fig. 1.1) were selected for collection of insect pests and subsequent examination of their mite associates. Of these, eight localities were selected from the Thrissur Dt., eight localities from the Palakkad Dt., 10 localities from the Malappuram Dt. and three localities from the Kozhikode Dt. A brief description of the collection districts has been presented below:

Thrissur district: With a geographical coverage of 3032 Km², Thrissur district is bounded on the north by the Palakkad district, on the east by the Coimbatore district of Tamil Nadu, on the South by the Kottayam and Ernakulam districts and on the West by the Lakshadweep sea. The district has an uneven topography with a westerly slope. The district is broadly divided into four geographic belts like: Charnockite belt, Gneissic belt, Granitic gneiss and Quarternaries of the coastal tract.

Palakkad district: The district constitutes about 11.5% of the state with 4480 Km². The district is divided into two natural divisions- highland and midland. Majority of the district falls under the midland region with valleys and plains. Areas like Nelliampathy-Parambikulam and Attappadi-Malampuzha fall in the highland region.

Malappuram district: The district is spread across 3550 Km² bounded by Nilgiri hills on the East, Arabian Sea on the West, Palakkad and Thrissur districts on the South. Topographically, the district includes three divisions; lowland, midland and highland with undulating geographical features, starting from hilltops along the Nilgiris and gradually sloping down in the West.

Kozhikode district: Situated on the South-West coast of India, the district is bordered by the Kannur district on the North, Wayanad district on the East, Malappuram district on the South and Arabian Sea on the West. The geographical area of the district extends over 2344 Km². The district is topographically divided into three regions such as rocky highlands, sandy region and lateritic midland.

Details of the collection localities selected from the four districts have been described below:

I. Collection localities

A. Collection localities in the Thrissur Dt.

1. Thachudaparambu (10°18'34.7"N 76°19'21.1"E): It is a small village in the outskirts of Chalakkudy town where there are many agricultural fields growing plantain, coconut and vegetables.
2. V. R. Puram (10°18'44.4"N 76°19'19.4"E): This site is adjacent to the previous site, Thachudaparambu where there are many organic agricultural fields growing paddy and horticultural crops.
3. Perambra (10°21'01.7"N 76°19'14.2"E): It is a small village situated near Chalakkudy town where some of the people still depend on own field grown rice and believe in healthier organic diet.
4. Kuzhikkani (10°22'15.3"N 76°19'15.1"E): This place includes more than 50 acres of land, with different varieties of paddy cultivations. During off-season, the people also grow vegetables here.
5. Kavanad (10°22'02.4"N 76°19'46.3"E): This area lies under the Aareshwaram mountain where modernity is still untouched and most of the inhabitants depend on agriculture for their livelihood. Here around 30 acres of land are under paddy cultivation.
6. Moolamkudam (10°23'19.8"N 76°19'33.4"E): It is a small village in the suburbs of Kodakara, the name of the place is attributable to the shape of the traditional 'kudam' meaning pot, surrounded by Kurumali river. Since water is plenty in this area, the main focus is given to cultivation of oil seeds like coconut, arecanut etc. and also some horticultural crops like plantain.
7. Vellanikkara (10°32'52.1"N 76°16'59.8"E): It is located near Mannuthy where the Campus of Kerala Agricultural University (KAU) is located. With

Table 1.1. Sampling localities surveyed for the collection of insect pest (hosts)

District	Sampling locality	Types of ecosystem surveyed
THRISSUR	1. Thachudaparambu	Banana plantation, kitchen garden
	2. V.R. Puram	Paddy field, vegetable field, kitchen garden
	3. Perambra	Paddy field
	4. Kuzhikkani	Paddy field
	5. Kavanad	Paddy field, vegetable field, kitchen garden
	6. Moolamkudam	Vegetable field, coconut plantation, kitchen garden
	7. Vellanikkara	Vegetable field
	8. Kuttikadu	Kitchen garden
PALAKKAD	9. Manissery	Paddy field, vegetable field, kitchen garden
	10. Kothayur	Paddy field, vegetable field, kitchen garden
	11. Killikavu	Paddy field
	12. Kanniyampuram	Vegetable field
	13. Panamanna	Paddy field, vegetable field, banana plantation
	14. Nedungottor	Vegetable field
	15. Pattambi	Paddy field
	16. Palappuram	Paddy field, vegetable field
MALAPPURAM	17. Muthoor	Paddy, vegetable field
	18. Vattamkulam	Kitchen garden
	19. Calicut University Botanical Garden	Botanical garden
	20. Villunniyal	Kitchen garden
	21. Kadakkattupara	Paddy field, vegetable field
	22. Thalappara	Paddy field, vegetable field
	23. Koottumoochi	Paddy field
	24. Padikkal	Paddy field
	25. Parappanangadi	Vegetable field
	26. Eezhuvathiruthi	Kitchen garden
KOZHIKODE	27. Vengeri	Vegetable field
	28. Thadambattuthazham	Kitchen garden
	29. Poovattuparambu	Vegetable field, banana plantation, kitchen garden

permission from the concerned authority the collection of pests attacking crops of various kinds was taken up.

8. Kuttikadu(10°33'15.5"N 76°16'41.1"E): This is the place situated along the cross-roads of Thrissur-Mannuthy Highway, near the KAU Campus where most of the house wives restrain to the practice of maintaining organic kitchen gardens and greenhouse crops. Collection of some common pests infesting cucurbits and chilli is permitted here also.

B. Collection sites in the Palakkad district

1. Manissery (10°46'43.1"N 76°20'26.2"E): It is a small village situated near the Thrissur-Palakkad Highway. Majority of the land area is under the cultivation of plantation crops like coconut, banana and different varieties of palms. In addition, paddy fields are also abundant in this area.
2. Kothayur (10°46'60.0"N 76°20'26.5"E): It is a remote village situated in the Palakkad district where three acres of land are under paddy cultivation. During the peak period of summer, the villagers practice the cultivation of vegetable crops, usually cucurbits as well as banana.
3. Killikavu (10°45'43.5"N 76°19'21.5"E): Located near the famous 'Varikkassery mana', this place is blessed with the aesthetic value and is very suitable for making collections of paddy pests. In having plenty of kitchen gardens with diverse types of vegetable crops like chilli, brinjal, cucurbits etc. this place is ideal for the collection of varied kinds of insect pests.
4. Kanniyampuram (10°46'37.4"N 76°21'01.2"E): It is a suburban area lying along the Palakkad National Highway where there are many pockets of village people practicing agriculture, mainly focusing on cultivation of paddy, banana and varieties of vegetable crops.
5. Panamanna (10°48'34.9"N 76°21'00.2"E): Located in the outskirts of Ottapalam, this place is a typical scenic view of a typical Palakkad village with oil palms and coconut. This area was found quite apt for setting up pheromone traps and light traps for collection of insect pests attacking plantation crops.

6. Nedungottoor (10°45'44.5"N 76°15'42.6"E): This locality is situated in the suburbs of the Palakkad district. This place holds several acres of land purely used for cultivation of paddy and vegetable crops.
7. Pattambi (10°48'41.7"N 76°10'36.1"E): It is a small township in Palakkad where paddy fields are very common in the suburbs.
8. Palappuram (10°46'16.8"N 76°24'31.6"E): This place is located near Ottapalam. Here about 20 acres of land is owned by a farmer who practices the cultivation of several endangered varieties of paddy, exclusively in the traditional organic way. The paddy fields in this area are thus quite suitable for making regular collection of paddy pests.

C. Collection sites in the Malappuram district

1. Muthoor (10°48'11.2"N 76°00'55.7"E): It is a small village situated in the pockets of Edappal town. The people of this area mainly practice the cultivation of paddy and during off-seasons, the paddy fields are used by the people for growing vegetable crops like cowpea, brinjal, okra and cucurbits.
2. Vattamkulam (10°47'19.4"N 76°01'35.0"E): This place is adjacent to Edappal. This place was found quite apt for the collection of vegetable pests as most of the house wives in this area used to grow vegetables in their kitchen gardens or in the premises of their houses.
3. Calicut University Botanical Garden (11°08'01.9"N 75°53'26.3"E): The Calicut University Botanical Garden is a biodiversity rich area which spreads over 19.5 ha. Collection of Lepidopteran pests, Coleopteran pests and also termites was made from the Botanical Garden of the Calicut University.
4. Villunniyal (11°07'39.7"N 75°53'14.0"E): Being an easily accessible site lying adjacent to the Calicut University Campus, this area was considered for collection of vegetable pests grown in the fields as well as in the kitchen gardens.
5. Kadakkattupara (11°07'48.8"N 75°52'49.7"E): It is a small village situated nearly 5 km away from the Calicut University Campus from where the collection of paddy pests was made from different paddy fields.
6. Thalappara (11°04'42.9"N 75°54'12.6"E): It is a place with extensive paddy fields, lying on either sides of the National Highway. There are more than 10 acres of land under the cultivation of different varieties of paddy along the

national highway. In addition, the farmers also cultivate banana and vegetables here.

7. Koottumooochi (11°05'22.1"N 75°52'14.2"E): It is located in the Kotakkad area of Malappuram Dt. This place also embraces vast areas of paddy fields which were found ideal for the collection of paddy pests required for the present investigation.
8. Padikkal (11°05'09.5"N 75°53'56.0"E): There are several small pockets of paddy fields in this area, where farmers used to cultivate mainly paddy and also vegetable crops to a certain extent. Considering this dual advantage, collection of insect pests attacking both paddy as well as vegetable crops was made from this locality.
9. Parappanangadi (11°03'04.4"N 75°51'32.1"E): It is a town located close to the Arabian sea. In this locality, there are some 12 acres of land under Krishi Bhavan, where green house crops and regular crops are cultivated. With prior permission, this area was also screened to collect insect pests required for the present study.
10. Eezhavathiruthi (11°03'04.4"N 75°51'32.1"E): This is a low lying area located near the sea in Ponnani, embracing a good number of coconut and banana plantations. Many coleopteran pests of banana and coconut included in the present study were collected from this area.

D. Collection sites in the Kozhikode district

1. Vengeri (11°17'45.0"N 75°47'23.9"E): This place is hardly 10 km away from the Calicut town. This site includes more than 10 acres of land, growing different varieties of vegetables like okra, brinjal, tomato, spinach and cucurbits. With the prior permission of concerned authorities, collection of insect pests infesting vegetable crops was made during the study.
2. Thadambattuthazham (11°17'50.8"N 75°47'35.7"E): With the support from the Agriculture Board, many houses in this area maintain kitchen gardens. Collection of many vegetable crop pests was possible from these kitchen gardens.

3. Poovattuparambu (11°16'11.4"N 75°53'05.3"E): It is a small village in the Kozhikode district from where collection of insect pests attacking paddy and vegetable crops was made

Insect Pests (Insect hosts) screened for documentation of mite associates

In the present study, a total of 29 species of insects belonging to 25 genera, 13 families and five orders viz. Coleoptera, Orthoptera, Hemiptera, Blattodea and Lepidoptera were screened for the documentation of faunal diversity of mites associated with them (Fig. 1.2, 1.3, 1.4, 1.5). As illustrated in table 1.2, two species from Orthoptera, three species from the order Blattodea, three species from the order Hemiptera, 17 species from the order Coleoptera and four species from the order Lepidoptera were collected.

III. Collection of insect pests (insect hosts)

The methods employed for the collection of insect pests included in the present study varied depending upon the differences in the habit, habitat, nature of infestation as well as morphological and behavioural characteristics of the pest species concerned (Table 1.3, Fig. 1.6). Accordingly, the collection methods used were passive or active or both. The passive collection methods involved the use of light traps and pheromone traps while the active collection methods employed were the use of insect nets as well as direct handpicking. During field sampling, care was taken to collect the different life stages of the host insects such as the adults, eggs, larval and pupal stages for subsequent microscopic examination of acarine associates. Further, utmost care was taken during the study to collect live specimens of the host insects/their life stages, in order to avoid the possibilities of the mite associates getting dislodged from the body of their insect hosts. Live specimens of the various life stages of the insect pests thus collected from their natural habitats using the insect net/light trap/hand picking were immediately transferred to plastic bottles of 30x10cm size. During sampling, infested parts of respective host plants were also collected along with the pests and placed in the bottles containing the pest specimens in order to supplement the respective dietary sources to support the survival of insects for subsequent laboratory examination. The collection bottles were closed properly with their lids to prevent the escape of the collected insect specimens. Adequate aeration was also provided in the collection bottles by putting side holes on the bottle. The collection bottles were labelled

Table 1.2. Insect species of agricultural/horticultural importance screened during the study

Sl. No	Species of insect pests	Order	Family	Host plants/ Crops attacked
1.	<i>Oxya chinensis</i> (Thunberg)	ORTHOPTERA	Acrididae	Paddy
2.	<i>Oxya hyla</i> Serville			”
3.	<i>Odontotermes feae</i> (Wasmann)	BLATTODEA	Termitidae	Wood
4.	<i>Odontotermes obesus</i> (Rambur)			Groundnut, sugarcane, sorghum, maize, barley, tea
5.	<i>Nasutitermes gardneri</i> Snyder			Rotten wood
6.	<i>Aleurothrixus floccosus</i> (Maskell)	HEMIPTERA	Aleyrodidae	Citrus, guava
7.	<i>Bemisia tabaci</i> (Gennadius)		Aleyrodidae	Annona, avocado, cabbage, chrysanthemum, guava, pumpkin, rose, soybean, cotton, chilli, edible gourds, eggplant, tomato, pepper, radish
8	<i>Leptocorisa acuta</i> (Thunberg)		Alydidae	Paddy
9.	<i>Altica</i> sp.	COLEOPTERA	Chrysomelidae	Paddy
10.	<i>Aulacophora foveicollis</i> (Lucas)			Cucurbits
11.	<i>Aulacophora frontalis</i> Baly			Cucurbits
12.	<i>Hoplasoma unicolor</i> (Illiger)			Cucurbits
13.	<i>Gonocephalus</i> sp.1		Tenebrionidae	Woody trees
14.	<i>Gonocephalus</i> sp.2			Paddy
15.	<i>Oryctes rhinoceros</i> (Linnaeus)		Scarabaeidae	Coconut, oil palm, sago palm
16.	<i>Onitis philemon</i> Fabricius			Nil

17.	<i>Copris repertus</i> Walker			Nil
18.	<i>Catharsius molossus</i> (Linnaeus)			Nil
19.	<i>Henosepilachna vigintioctopunctata</i> (Fabricius)		Coccinellidae	Solanaceous crops
20.	<i>Batocera rufomaculata</i> (De Geer)		Cerambycidae	Mango, cashew, papaya, sal tree
21.	<i>Xystocera globosa</i> (Olivier)			Woody trees
22.	<i>Cosmopolites sordidus</i> (Germar)		Curculionidae	Banana
23.	<i>Odoiporus longicollis</i> Oliver			Banana
24.	<i>Rhynchophorus ferrugineus</i> Oliver			Coconut, date palm, oil palm
25.	<i>Sternochetus mangiferae</i> (Fabricius)			Mango
26.	<i>Melanitis leda ismene</i> Linnaeus	LEPIDOPTERA	Nymphalidae	Paddy, bamboos, wire grass
27.	<i>Pelopidas mathias</i> (Fabricius)		Hesperiidae	Paddy
28.	<i>Cnaphalocrocis medinalis</i> Guenee		Crambidae	Paddy
29	<i>Scirpophaga incertulas</i> (Walker)		Pyralidae	Paddy

Table 1.3. Methods employed for collection of different life stages of insect pests (hosts)

Sl. No.	Species of Insect Pests collected	Collection methods employed	Life stages of insect pests collected
1.	<i>Oxya chinensis</i>	Insect net	Adult
2.	<i>Oxya hyla</i>	Insect net	Adult
3.	<i>Odontotermes feae</i>	Handpicking	Adult
4.	<i>Odontotermes obesus</i>	Handpicking	Adult
5.	<i>Nasutitermes gardneri</i>	Handpicking	Adult
6.	<i>Aleurothrixus floccosus</i>	Handpicking	Egg, nymph, adult
7.	<i>Bemisia tabaci</i>	Handpicking	Egg, nymph, adult
8.	<i>Leptocorisa acuta</i>	Insect net	Adult
9.	<i>Altica</i> sp.	Insect net	Adult
10.	<i>Aulacophora foveicollis</i>	Insect net	Adult
11.	<i>Aulacophora frontalis</i>	Insect net	Adult
12.	<i>Batocera rufomaculata</i>	Light trap	Adult
13.	<i>Catharsius molossus</i>	Light trap	Adult
14.	<i>Copris repertus</i>	Light trap	Adult
15.	<i>Cosmopolites sordidus</i>	Handpicking	Adult
16.	<i>Gonocephalus</i> sp.1	Handpicking	Adult
17.	<i>Gonocephalus</i> sp.2	Light trap	Adult
18.	<i>Henosepilachna vigintioctopunctata</i>	Handpicking	Adult
19.	<i>Hoplasoma unicolor</i>	Insect net	Adult
20.	<i>Odoiporus longicollis</i>	Handpicking	Adult
21.	<i>Onitis philemon</i>	Light trap	Adult
22.	<i>Oryctes rhinoceros</i>	Light trap, pheromone trap, handpicking	Egg, larva, adult
23.	<i>Rhynchophorus ferrugineus</i>	Light trap, pheromone trap, handpicking	Egg, larva, adult
24.	<i>Sternochetus mangifera</i>	Handpicking	Adult
25.	<i>Xystocera globosa</i>	Light trap	Adult
26.	<i>Cnaphalocrocis medinalis</i>	Handpicking	Larva
27.	<i>Melanitis leda ismene</i>	Insect net	Adult
28.	<i>Pelopidas mathias</i>	Insect net	Adult
29.	<i>Scirpophaga incertulas</i>	Handpicking, insect net	Larva, Adult

appropriately in the field itself, providing data on the date of collection, place of collection, host plant, life stage collected etc. Data were also recorded on the total number of insects collected under each species and from each of the sampling locality. The bottles containing the insects were transported to the laboratory with minimum disturbance, for subsequent examination of their body parts under a stereomicroscope to locate the mite specimens associated with the different parts of the insect body. During transportation of collected insect specimens from the field to the laboratory, proper care was taken to avoid exposure to sunlight and heat.

In the laboratory, the insect specimens were inactivated by keeping the collection bottles in a refrigerator for about 15 minutes. The inactivated insect specimens were then carefully examined individually, under a stereozoom microscope (Labovision KS z0850) to locate the associated mite specimens, if any. Simultaneously, identification of individual species of insect pest was also made following taxonomic keys and relevant literature and also by seeking help from experts. The mite specimens located upon microscopic examination on the various body parts of the host insects were segregated with the help of a moistened camel hairbrush (size zero) and transferred to a cavity block containing 70% alcohol for further taxonomic studies.

IV. Studies on population density and distribution pattern of the different life stages of mite associates on the various body parts of insect hosts

In the laboratory, the different regions of the body of the host insect specimens were thoroughly examined under a stereozoom microscope (Labovision KS z0850) in order to record data on the preferred sites of attachment of mite associates on the body parts of host insects, population density of the various taxa of mites on the specific body parts of host insects, the various life stages of mite associates etc. Quite often, the body parts of host insects were torn off to locate the mite associates present on the hidden body parts and also to count the number of mites present on the individual part of the insect body. The population density of the various species of mites on the different body parts of the insect hosts was determined separately by counting the number of mites present on the specific regions of the body of individual species of insect hosts. The data gathered on the population density of individual species of mite associates on the different body regions of individual species of insect host were subjected to statistical analysis, using KS test of normality. For analysing the preferred

sites of attachment of mites on the body of host insects, non- parametric test (Kruskal-Wallis test) using IBM-SPSS software was followed, as the data were not found to follow normal distribution.

In order to study the nature of mite infestation and its impact on the body of insect hosts, detailed microscopic examination was carried out to locate the traces of feeding symptoms , if any, such as the presence of feeding punctures/ scars, oozing out of haemolymph etc. The insect specimens which got damaged during microscopic examination were discarded, after recording relevant data on mite infestation and the intact ones were reared in the laboratory for making further observation on the developmental parameters of the mites on the body of the host insects. During laboratory rearing, the pest infested parts of the host plant collected from the field were offered as the food source in aerated plastic bottles. Regular observation was made to record data on the nature of association of mites with the insect hosts, until the death of the insects or their mite associates. Renewal of plant parts as well as removal of fecal pellets was done at regular intervals to keep the host insects alive in the rearing bottles. In order to confirm the preliminary data recorded on the various life stages of mites associated with host insects, slide mounts of individual mite specimens were prepared for detailed taxonomic studies.

V. Taxonomic studies on the mite associates collected from the insect hosts

a. Preservation, Dehydration and clearing of specimens

For taxonomic studies, mite specimens segregated from different body regions of the insect hosts using a camel hair brush were preserved in 70% alcohol. The preserved mite specimens were then dehydrated subsequently by passing through alcohol series of 80%, 90% and absolute alcohol. The weakly sclerotised specimens (several species of Prostigmata and Astigmata) were directly slide mounted in Hoyer's medium, without subjecting to dehydration and clearing procedures. Moderately/heavily sclerotised specimens, especially those of Mesostigmata were transferred to a clearing medium, prepared by mixing absolute ethyl alcohol and lactic acid in the ratio of 1:1. Sufficient time was given for clearing of the specimens, depending upon the degree of sclerotisation of individual species. The cleared specimens were then slide mounted in Hoyer's medium for further taxonomic studies.

i. Preparation of Mounting medium (Hoyer's medium- Walter and Krantz, 2009)

Being a mounting as well as clearing medium, Hoyer's medium was used during the present study, for the preparation of permanent slide mounts of the mite specimens collected from the insect hosts. Hoyer's medium was prepared using the following ingredients, as detailed below:

Gum Arabic	: 30g
Chloral hydrate	: 200g
Distilled water	: 50ml
Glycerol	: 20ml

The above ingredients were transferred to a 500 ml beaker and gently warmed on a heater with frequent stirring, until they got completely dissolved. The solution was then cooled to room temperature. The mixture was then filtered through cotton, and stored in an amber coloured bottle to be used for the mounting of mite specimens.

b. Preparation of slide mounts of mite specimens

A small drop of Hoyer's medium was placed at the centre of a microscopic slide. Using a camel hairbrush, dehydrated and properly cleared mite specimens were carefully transferred species-wise to the mounting medium on the slide. The mite specimen was then oriented along the antero-posterior axis, on the slide with the legs stretched outwards properly and the mouthparts positioned appropriately. In order to prevent the crushing of specimens, small glass bristles were placed, adjacent to the specimen on the slide, before placing the coverslip. Then, the cover slips were laid over the specimen with utmost care to avoid trapping of air bubbles. The slide mounts were labelled properly, giving data on the date of collection, place of collection, name of insect host, name of collector etc. and were kept in an oven at 30°C for one to two weeks, depending upon the degree of sclerotisation. When the specimens attained sufficient clarity, the slide mounts were sealed by ringing with nail polish to prevent the entry of traces of atmospheric moisture or mould formation, and stored in slide boxes.

c. Identification of mite specimens

The cleared mite specimens were identified upto the family level following the general identification keys to various acarine taxa available in the 'Manual of Acarology' authored by Krantz and Walter (2009). For generic/species level identification, the slide mounted specimens were thoroughly examined under a compound microscope (Labovision Sense i4000) to compare its morphological characters with those of related species mentioned in the identification keys available in Hughes (1976), Gupta (2003) and other relevant research publications. Confirmation of species identity of various species of mites was done seeking the help of experts. Photographs and measurements of slide mounted mite specimens were taken using a compound microscope (Zeiss Scope AX 1). The morphological features of the slide mounted specimens of various species of mites were drawn using a prism type camera lucida mounted on a monocular Unitron research microscope and the measurements and scaling of individual species were made using an ocular micrometer. The final drawing was made using the software Adobe illustrator.

d. Preparation of mite specimens for SEM photography

The mite specimens preserved in 70% alcohol were dehydrated by passing through ethanol series of 80%, 90% and 100% followed by acetone. The dehydrated specimens were then mounted on the electron microscopic stub using a fine needle and were properly oriented. The stub was then placed in an oven for 24 hours to ensure complete dehydration and subsequently sputtered with gold. The specimens were then examined under the Gemini Scanning Electron Microscope available at the Central Sophisticated Instrument Facility, University of Calicut and photographed.

VI. Assessment of the impact of phoretic load of mites on the body weight of the insect hosts

In the present study, the impact of phoretic mite load on the body weight of respective insect hosts was assessed in three representative species of insect pests like the weevil/beetle hosts viz. *Odoiporus longicollis*, *Oryctes rhinoceros* and *Rhynchophorus ferrugineus*, by recording the difference in their body weights before and after removal of mites from all parts of their body. The selection of the above three species of insect hosts was made duly considering the fairly good number of

mites harboured by them. Prior to counting the number of phoretic mites, the host insects were frozen for 30 minutes by keeping them in a refrigerator. The number of mites present on the body of the insect host was counted under a stereozoom microscope. Data on the body weight of the individual species of insect host with mites were recorded first. Afterwards, the mites were completely removed from the body of insect hosts using an entomological pin under a stereomicroscope and the body weight of the insects without mites was again taken. The difference in the body weight of the insects was recorded and statistically analysed following the Wilcoxon Signed Rank Test. Correlation between the number of mites and the weight difference of the weevil was noted and the data were used to plot a correlation graph.

VII. Laboratory rearing, elucidation of mite-host association and life cycle parameters of *Histiostoma furrowa* sp. nov., a phoretic species displaying facultative necromeny on *Odoiporus longicollis*

Laboratory rearing of a selected species of acarine associate, viz. *H. furrowa* sp. nov. which showed facultative necromeny on its host insect, *O. longicollis*, the notorious weevil pest of banana, was performed on four different media viz.

1. Cut piece of banana pseudostem
2. Paper discs overlaid with yeast solution
3. Decapitated carcass of the weevil
4. Carcass of weevil placed on banana pseudostem

Rearing of the mite was carried out in the laboratory on the above four media placed in containers at a temperature of $27\pm 2^{\circ}\text{C}$ and 75 ± 3 RH in screw top containers (Fig. 1.7 A). Medium 1 (decapitated carcass) was used to check the probable incidence of necromeny while the medium 4 (carcass placed on the banana pseudostem) (Fig. 1.7 B) was kept to confirm the feeding preference of the mite, either towards the carcass or towards the pseudostem. Ten replicates were kept for each of the above experiment, with five deutonymphs per container. A cotton ball saturated with distilled water was placed under the pseudostem as well as the dead weevil specimen to prevent dehydration. To ensure constant supply of *O. longicollis* infested with *H. furrowa* sp. nov., the weevils were maintained in the laboratory in aerated plastic bottles with pseudostem as food supply for the weevils (Fig. 1.7 D).

Studies on the life cycle of *H. furrowa* sp. nov. were carried out on paper discs overlaid with yeast solution ($27\pm 2^{\circ}\text{C}$ and 75 ± 3 RH). The mites were reared in capped polystyrene bottle of 1cm length and 1.5 cm diameter (Fig. 1.7 C) with a filter paper substratum saturated with yeast solution. This medium was preferred over the pseudostem for biological studies, as the latter was proved to serve as excellent hideaways for the developing stages of the mite. Ten replicates were kept for each of the experimental setup for confirmation of results. Optimum moisture condition was maintained in the culture cell by the daily addition of freshly prepared yeast solution. The culture cells were incubated at $27\pm 2^{\circ}\text{C}$ and $75\%\pm 5$ RH.

Larvae emerged within 6 hours of larviposition were segregated and transferred singly into each of the culture cell in order to gather information on duration of the life cycle of the mite species. Since the deutonymphal stage was found skipped under laboratory conditions, individual culture cells were also maintained for the deutonymphs to determine the duration of deutoquiescence (DQ) and interval between DQ and that of the tritonymph. Observations were made at a time interval of 3 hours. Sex ratio of the species was determined by placing single mated females on separate culture cells and rearing their offsprings to reach the adulthood. The occurrence of parthenogenesis was also tested by isolating virgin females in culture cells.

Chapter 4

Observation

During the three year period (2017-2020) of sampling, 29 species of insects belonging to 25 genera, 14 families and five orders viz. Coleoptera, Orthoptera, Hemiptera, Blattodea and Lepidoptera were subjected to microscopic examination in order to record the presence of mite associates, if any, associated with them. Of the 29 species of insects screened, 24 species were found to host different species of mite associates, thereby enabling to record 82.75% of mite infestation (Table 1.4). As presented in table 1.4, five species showed a total absence of mite association and the species which disclosed negative sign of mite infestation were *Leptocorisa acuta* (Hemiptera), *Sternochetus mangiferae* (Coleoptera), and the three Lepidopteran species like *Pelopidas mathias*, *Cnaphalocrocis medicinalis* and *Scirpophaga incertulas*. As evident from table 1.4, both the species of orthopteran insects examined disclosed the presence of mite associates. Similarly, all the three species of termites collected and examined during the study revealed the presence of mites on their body. Among the three species of hemipterans examined, the rice bug, *L. acuta* was found devoid of any mites while both the species of white flies viz. *Bemisia tabaci* and *Aleurothrixus floccosus* revealed the presence of mites on their body. Of the total 17 species of coleopteran insects examined, all the species except the mango weevil, *Sternochetus mangiferae* showed the presence of mites on their body. Lepidopteran species were found more resistant to mite infestation as evidenced during the study. A total of four species of lepidopterans comprising two species of butterflies (*Melanitis leda ismene* and *P.mathias*) and two species of moths (*C. medinalis* and *S. incertulas*) were examined and mite association was recognized only in the butterfly species, *M. leda ismene*.

As evidenced from table 1.4, the maximum species with positive signs of mite association was observed under the order Coleoptera (17 spp.) and the minimum was observed under the order Lepidoptera (one species). Based on the number of species showing mite infestation, the five orders of insects screened during the study could be

presented in the downward sequence of Coleoptera>Blattodea>Orthoptera =Hemiptera > Lepidoptera.

The level of mite infestation was found variable among the 24 species of insects which harboured mites on their body. As shown in table 1.4, the intensity of infestation was the maximum on the rhinoceros beetle, *O. rhinoceros* which harboured the maximum number of mite species, usually hosting over 10 species by the individuals in most cases. The white fly species, *B. tabaci* (Hemiptera) and the red palm weevil, *R. ferrugineus* (Coleoptera) shared the second position by harbouring 6-10 species of mites on the different regions of their body. The third position was shared by 12 species (Table 1.4) by hosting 2-5 species of mites on their body and seven species harboured a single species each, thereby reaching the last position.

Results of the studies on the faunal diversity and species composition of mites associated with the 24 species of insects disclosed the presence of 65 species of mites belonging to under three orders and two superorders of the subclass Acari. Details of the systematic position, faunal composition and species diversity of the mites associated with the various insect hosts have been described below, along with identification keys to the species recovered under various families.

A. Faunal diversity and species composition of mites recovered from the Insect hosts screened during the study

Results of taxonomic analysis of the mites recovered from the insects representing the five orders enabled to identify 65 species categorised under 42 genera, 26 families, 19 superfamilies, 3 orders and 2 superorders of the subclass Acari (Table 1. 5). As presented in table 1.5, 52% of the total mites collected could be allocated to the superorder Parasitiformes and 48% were recognized as members of Acariformes (Fig. 1.8). Despite the dominance in the percentage composition, the superorder Parasitiformes was found to comprise members of a single order viz. Mesostigmata, whereas the Acariformes was found to include representatives of two orders viz. Trombidiformes and Sarcoptiformes. The mesostigmatid mites collected from the various insect hosts were found to represent 34 species, belonging to 18 genera, 10 families and seven superfamilies. Under the superorder Acariformes, 31 species belonging to 24 genera, 15 families and 11 superfamilies were recovered, distributed under the orders, Trombidiformes and Sarcoptiformes. The dominance of

Sarcoptiformes was evident as it constituted 28% of the mites and the Trombidiformes was found represented by 20% of the collected mite species. The most dominant superfamilies recognized during the study were Phytoseioidea (Parasitiformes) and Acaroidea (Acariformes), each accommodating 9 species each.

The order Mesostigmata was found represented by mites belonging to two suborders viz. Trigynaspida and Monogynaspida in which the former included mites of a single family, thereby constituting less than 6% of the total Mesostigmata while the latter constituted 94% of mites classified under 9 families. As indicated in table 1.5, the mites collected under the suborder Trigynaspida were found to include two new species viz. *Tridiplogynium rhynchophora* sp. nov. and *Schizodiplogynium rhinocera* sp. nov. Among the 9 families recovered under the suborder Monogynaspida, Phytoseioidea was the most dominant superfamily, comprising mites representing two families (Fig. 1.9) viz. Phytoseiidae and Blattisociidae. Among the two families of Phytoseioidea, the Phytoseiidae was found represented by seven species belonging to four genera viz. *Amblyseius*, *Euseius*, *Transeius* and *Neoseiulus* while the family Blattisociidae was found to include two species belonging to a single genus, *Lasioseius*. Of the four genera of Phytoseiidae recovered during the study, *Amblyseius* was the dominant, comprised of three species viz. *A. channabasavannai*, *A. largoensis* and *A. vasiformis*. The genus *Euseius* contained two species, *E. finlandicus* and *E. ovalis*. The genera *Transeius* and *Neoseiulus* were represented by a single species each viz. *T. kroeffi* and *N. mapuche* respectively. The genus *Lasioseius* of the family Blattisociidae was found to accommodate two species including a new one, and the species were *L. confusus* and the novel species *L. (L.) moolamkudensis* sp. nov. Under the suborder Mesostigmata, Uropodoidea was recognized as the second most abundant superfamily after Phytoseioidea (Fig. 1.9), comprising two families, Uropodidae and Dinychidae. The family Uropodidae was found to include four species, three of which belonging to genus *Uropoda* viz. *U. heliocopridis*, *U. orbicularis*, *U. shangaica* and one species of *Centrouropoda* viz. *C. almerodai*. The family Dinychidae was found to include four species under a single genus, *Uroobovella* and the species recovered were *U. assamomarginata*, *U. javae*, *U. phoenicicola* and *U. pilosetosa*.

Eviphidoidea formed the next abundant superfamily with two families, Eviphididae and Macrochelidae. Of these two, Eviphididae was composed of two species, under

the genus *Alliphis* while the family Macrochelidae was represented by four species under a single genus *Macrocheles*, *M. glaber*, *M. krantzi*, *M. muscaedomesticae* and *M. perglaber*. Dermanyssoidea, with a single family Laelapidae was the dominant superfamily, next to Eviphidoidea and it included five species under three genera viz. *Laelaps*, *Hypoaspis* and *Dinogamasus*. Of these, *Laelaps* and *Dinogamasus* showed representation by a single species, while *Hypoaspis* was represented by three species like *H. heselhousi*, *H. sardous*, *H. subterranea*. The family diversity of Parasitoidea and Rhodacaroidae was comparatively very low and showed representation by a single family each, viz. Parasitidae and Digamasellidae. Of these, Parasitidae included two genera, *Holoparasitus* and *Poechilochirus*, both represented by a single species each viz. *H. stramenti* and *Poechilochirus* sp. Digamasellidae was found to comprise two species belonging to a single genus viz. *Digamasellus* and the species recovered were *D. neodisetus* and *D. quadrisetus*. The generic composition of mites recovered under the various families showed a different trend when compared to the numerical abundance of species under each superfamily (Fig. 1.10). As shown in fig. 1.10, the family Phytoseiidae showed the maximum generic diversity, accommodating four genera, followed by the family Laelapidae (with three genera). This was followed by Diplogyniidae, Uropodidae and Parasitidae, each with two genera and the remaining families contained a single genus each. Based on their generic composition, the various acarine families recovered from the insect hosts could be arranged in the downward sequence of Phytoseiidae>Laelapidae>Diplogyniidae=Uropodidae=Parasitidae>Dinychidae=Digamasellidae=Eviphididae=Macrochelidae=Blattisociidae.

Though the order Trombidiformes constituted only 20% of the collected species, the family and generic diversity was high, as it included 9 families and 10 genera. The superfamily Tarsonemoidea encompassed two families, Podapolipidae and Tarsonemidae. The family Podapolipidae consisted of two genera like *Locusatacarus* and *Podapolipus* each with two novel species viz. *L. chinensis* sp. nov. and *P. palappuramensis* sp. nov. The family Tarsonemidae was found to include a single species viz. *Steneotarsonemus brasiliensis*.

The superfamilies Bdelloidea and Tarsocheyleyoidea were found to include a single family each, the former containing Cunaxidae and the latter with Tarsocheylidae, each with two species. The two species recovered under Cunaxidae were *Cunaxa anomala* and *C. heterostriata* while Tarsocheylidae was found to include a single genus viz.

Hoplocheylus, the latter also was found to accommodate two species, *H. longispinus* and *H. zanzibarensis*. The remaining families like Erythraeidae, Trombidiidae, Cheyletidae, Dolichocybidae, Microdispidae and Pygmephoridae harboured a single species each. The species collected under the above genera were *Leptus treati*, *Neosilphitrombium gratum*, *Cheyletus kuznetsovi*, *Pavania foliata*, *Premicrodispus paramaevi* and *Pygmephorellus indicus* sp. nov. respectively. The generic diversity in each family was found to be very low as represented in Fig. 1.11. All the families except Podapolipidae were found to harbour a single genus each.

Members of the order Sarcoptiformes accounted for 28% of the total mite species collected from the insect hosts examined during the study. The family diversity of Sarcoptiformes was very low as it harboured members of only six families (Fig. 1.12), but the order presented a relatively rich generic diversity. The most species rich superfamily recognized under Sarcoptiformes was Acaroidea, and it harboured nine species under two families viz. Acaridae and Suidasiidae. Acaridae was the dominant family holding eight species grouped under seven genera viz. *Acarus*, *Rhizoglyphus*, *Acotyledon*, *Sancassania*, *Schweibea*, *Caloglyphus* and *Tyrophagus*. The eight species recovered under the above genera were *Acarus solimani*, *Rhizoglyphus vicantus*, *Acotyledon tariqi*, *Sancassania boharti*, *Schweibea* sp., *Caloglyphus manuri*, *C. subteraneousi* and *Tyrophagus putrescentiae*. The family Suidasiidae was represented by a single species, *Sapracarus* sp. The superfamily Histiostomatoidea was found to include a single family Histiostomatidae, and which formed the second dominant superfamily of the order Sarcoptiformes, presenting five species under two genera such as *Histiostoma* and *Curculanoetus*. The genus *Histiostoma* comprised of four species, *H. herballi*, *H. maritimus*, *H. sammari* and *H. furrowa* sp. nov. while the genus *Curculanoetus* included a single species, and which could be recognized as a new species viz. *C. keralensis* sp. nov. The remaining two superfamilies of Sarcoptiformes viz. Canestriniodea and Hemisarcoptoidea were represented by two species each. The former superfamily included a single family, Canestriniidae and two genera viz. *Canestriniella* and *Athogavia* were identified under this family. Both the above genera were found to contain a single species each, and both of them could be recognized as new taxa viz. *C. batocera* sp. nov. and *A. oryctae* sp. nov. The superfamily Hemisarcoptoidea was found to comprise members of two families viz. Hemisarcoptidae and Winterschmidtidae and both of which had representation by a

single genus each viz. *Congovidia* and *Procalvolia*. Both the genera were found to hold a single species each viz. *C. glossinae* and *Procalvolia* sp. respectively.

The results of the faunal survey conducted during the study enabled to identify 10 new species viz. *T. rhynchophora* sp. nov., *S. rhinocera* sp. nov., *L. moolamkudensis* sp. nov., *P. indicus* sp. nov., *P. palappuramensis* sp. nov., *L. chinensis* sp. nov., *H. furrowa* sp. nov., *C. keralensis* sp. nov., *C. batocera* sp. nov. and *A. oryctae* sp. nov. (Table 1.6). Further, the study could record new association of 59 species of mites with so far unreported insect hosts. This shows that majority of the species associations formed the first host record. 55 species collected formed the first report from India (Table 1.5). The mites which were recorded for the first time from insect hosts could be listed as; *U. pilosetosa*, *M. perglaber*, *N. mapuche*, *H. stramenti*, *L. confusus*, *M. glaber*, *H. heselhousi*, *C. kuznetsovi*, *H. longispinus*, *H. zanzibarensis*, *S. brasiliensis*, *H. herbali*, *R. vicantus*, *A. tariqi*, *T. rhynchophora* sp. nov., *S. rhinocera* sp. nov., *L. (L.) moolamkudensis* sp. nov., *P. indicus* sp. nov., *P. palappuramensis* sp. nov., *L. chinensis* sp. nov., *H. furrowa* sp. nov., *C. keralensis* sp. nov., *C. batocera* sp. nov. and *A. oryctae* sp. nov. Six phytoseiid species like *A. channabasavannai*, *A. largoensis*, *A. vasiformis*, *E. finlandicus*, *E. ovalis*, *T. kroeffi* and two cunaxid members like *C. heterostriata* and *C. anomala* could be reported for the first time from chilli infested with *B. tabaci*. The mite species like *M. muscaedomesticae*, *H. sammari*, *C. glossinae*, *T. putrescentiae*, *Procalvolia* sp., *Dinogamasus* sp., and *Laelaps* sp., *Poechilochirus* sp. formed the first report from the order Coleoptera while the mesostigmatid mite, *A. halleri* formed the first time record from the order Lepidoptera. The species like *P. paramaevi*, *C. manuri*, *Schweibea* sp. and *Sapracarus* sp. formed first report from the order Blattodea.

B. Relative abundance of the various taxa of mites associated with insect hosts

Table 1.5 presents the details of the acarine fauna associated with the various species of insects examined during the study. Results of the extensive survey revealed that the acarine fauna associated with each species of insect could vary in their numerical density and taxonomic diversity. Details of the number of various taxa of mites such as the families, genera and species associated with respective insect hosts were shown in Table 1.7. As indicated in Table 1.7, the maximum number of mite species was found harboured by the beetle host, *O. rhinoceros*. Similarly, the numerical abundance

of the acarine family and genus was found highest on *O. rhinoceros*. A total of 11 families, 13 genera and 13 species were collected from *O. rhinoceros*, thereby accounting for 16.45% of all the mite taxa collected. The 13 species including two new species recovered from *O. rhinoceros* were *S. rhinocera* sp. nov., *U. heliocopridis*, *L. confusus*, *H. sardous*, *H. sammari*, *A. oryctae* sp. nov., *S. boharti*, *T. putrescentiae*, *H. stramenti*, *D. neodisetus*, *M. perglaber*, *Laelaps* sp. and *A. tariqi* (Fig. 1.13). The red palm weevil, *R. ferrugineus* reached the second position in supporting the maximum acarine taxa by hosting 10 species of mites (including two new species) belonging to seven genera and seven families, thereby encompassing 12.65% of the total taxa of mites collected from insects (Fig. 1.14, Fig. 1.15). The species recovered from the above insect host included *T. rhynchophora* sp. nov., *C. almerodai*, *U. assamomarginata*, *U. phoenicicola*, *U. javae*, *D. quadrisetus*, *Dinogamasus* sp., *M. krantzi*, *M. perglaber* and *C. keralensis* sp. nov. 11.39% of the mite species was collected from chilli plants infested with *B. tabaci* (Fig. 1.16). The nine species collected from chilli plants were categorized under five genera and three families and the species were identified as *L. (L.) moolamkudensis* sp. nov., *A. largoensis*, *A. channabasavannai*, *A. vasiformis*, *E. ovalis*, *E. finlandicus*, *T. kroeffis*, *C. anomala* and *C. heterostriata*.

The dung beetle, *Copris repertus* was found to harbour more than 6.32% of all the collected species of mites, represented by five species belonging to five genera and four families. The order Blattodea comprising three species of termites hosted about 14% of the total mite species collected (Fig. 1.17). Of this, *N. gardneri* and *O. feae* were found to harbour 5.06% each of the mite species while 3.79% was collected from *O. obesus*. The four species collected from *N. gardneri* included *A. solimani*, *A. tariqi*, *C. manuri* and *Sapracarus* sp. while those collected from *O. feae* were *P. paramaevi*, *R. vicantus*, *Schweibea* sp. and *C. subterraneousi*. The mites collected from *O. obesus* could be listed as *R. vicantus*, *S. boharti* and *H. herbali*.

The orthopteran pest, *O. hyla* harboured 5.06% of the total mites, with the species recovered being *N. mapuche*, *L. treati*, *S. brasiliensis* and *P. palappuramensis* sp. nov. (Fig. 1.18) More than 3% (3.79) of mites were found lodged by dung beetles like *O. philemon* and *C. molossus* and the mite associates of which were *U. pilosetosa*, *M. glaber*, *H. zanzibarensis*, *H. stramenti*, *Poecilochirus* sp., *M. krantzi*, *H. subterranea*, *P. indicus* sp. nov. (Fig. 1.19 B), *Alliphis* sp., *H. heselhousei* (Fig. 1.19 A) and *P.*

foliata. The coleopteran member, *B. rufomaculata* carried 3.79% of the total mites collected. The mite species recovered were *U. orbicularis*, *N. gratum* and *C. batocera* sp. nov. (Fig. 1.20). Insects like *O. longicollis*, *C. sordidus*, *A. foveicollis*, *H. vigintioctopunctata* and *O. chinensis* were found to harbour 2.53% of the total mites collected. The two species collected from *O. longicollis* and *C. sordidus* were *M. muscaedomesticae* and *H. furrowa* sp. nov. (Fig. 1.21). The insect, *A. foveicollis* harboured two species, *H. sammari* and *Procalvolia* sp. (Fig. 1.22) while *H. vigintioctopunctata* showed association of two species viz. *H. maritimus* and *C. glossinae*. The two species recovered from *O. chinensis* were *L. treati* and *L. chinensis* sp.nov.

The lowest number of mite species were recovered from insects like *X. globosa* (viz. *U. shangaica*) (Fig. 1.19 F), *A. frontalis* (viz. *H. sammari*), *H. unicolor* (viz. *Procalvolia* sp.) (Fig.1.22), *Altica* sp. (viz. *H. maritimus*) (Fig. 1.22), *Gonocephalus* sp. 1 (viz. *C. kuznetsovi*) (Fig. 1.19 D), *Gonocephalus* sp. 2(viz. *H. longispinus*) (Fig. 1.19 C), *M. leda ismene* (viz. *A. halleri*) and *A. floccosus* (viz. *A. largoensis*), each of the above insect species carried less than 2% of total mites collected ie one species.

Results of the study revealed that coleopteran insects served as hosts for a major share of mite associates, by revealing the association of more than 50% of mites (64%) with their body parts (Fig. 1.23). Among the various taxa of mites associated with the order Coleoptera, 26 species were representatives of order Mesostigmata, 10 species were members of order Sarcoptiformes and 6 species belonged to order Trombidiformes (Fig. 1.24). The insect orders like Blattodea and Hemiptera disclosed the association of more than 10% of mite species. 14% of the collected mites showed association with Blattodea while 13% were seen in association with Hemiptera. Among 10 species of mites associated with Blattodea, nine belonged to order Sarcoptiformes and one was from the order Trombidiformes. Seven out of the nine species of mites recovered from Hemiptera were Mesostigmata while the remaining two species were members of Trombidiformes. The insect order Orthoptera revealed the presence of 8% of the total mite species, of which four species were members of order Trombidiformes and one species belonged to Mesostigmata (Fig. 1.24). The lowest number of mite species was detected in Lepidopteran insects, thereby constituting only 1% of total mites collected (Fig. 1. 23). The single mite species collected from Lepidoptera belonged to the order Mesostigmata (Fig. 1.24).

C. Life stages of mites associated with insect hosts and the types of insect-mite associations

During the present study, varied life stages of mite associates were encountered in association with the insect hosts examined and their nature of association with respective hosts also showed variation (Table 1.8). Majority of the mite species recovered during the study from the insect hosts screened were observed to be the adult females and this was applicable for 28 species of mites (Fig. 1.25) out of the 65 species collected. In the present study, 28 species from two orders viz. Mesostigmata (19 species) and Trombidiformes (9 species) were proved to have established their association with insect hosts in their adult female stage (Fig. 1.26). In the order Sarcoptiformes, the adult females were found to exhibit a parasitic association, along with all other life stages and hence presented separately. The highest number of adult females associated with insects was recorded among the families of the order Mesostigmata. Under Mesostigmata, the six species of Phytoseiidae viz. *A. channabasavannai*, *A. largoensis*, *A. vasiformis*, *E. finlandicus*, *E. ovalis* and *T. kroeffis* were collected in their adult female stage and their association could be recorded with the hemipteran pests like *B. tabaci* and *Aleurothrixus floccosus*. In the family Macrochelidae, adult female was the only stage collected as observed in all the four species viz. *M. krantzi*, *M. perglaber*, *M. muscaedomesticae* and *M. glaber*. All the recovered species showed association with the coleopteran pests viz. *R. ferrugineus* and *O. longicollis* as well as dung beetles like *O. philemon* and *C. repertus*. The adult females of three species belonging to the genus *Hypoaspis* viz. *H. heselhousi*, *H. sardous* and *H. subterranean* of the family Laelapidae were found associated with the beetle pest, *O. rhinoceros* as well as dung beetles like *C. repertus* and *C. molossus*. From the families Diplogyniidae and Blattisociidae all the species collected were in their adult female stage. The species collected from the above families were *S. rhinocera* sp. nov. associated with *O. rhinoceros*, *T. rhynchophora* sp. nov. associated with *B. rufomaculata*, *L. confusus* associated with *O. rhinoceros* and *L. (L.) moolamkudensis* sp. nov. associated with *B. tabaci*. The families like Dinychidae and Eviphididae were represented by single species each in their adult female stage. The species included *U. pilosetosa* and *A. halleri* respectively, and were found associated with insects like *O. philemon* and *M. leda ismene* respectively. In the order Trombidiformes, only 32% of the mites showed

insect association in their adult female stage. Families like Cunaxidae, Tarsocheylidae and Pygmephoridae were found represented by two species each while the families Cheyletidae, Microdispidae and Tarsonemidae were represented by a single species each and all exhibited insect association in their adult female stage (Table 1.8).

The second most abundant life stage associated with insects revealed during the study was the deutonymphal stage. 27 species of mites were solely represented by the deutonymphal stage. The deutonymphal stage of various species of mites belonging to orders Mesostigmata and Sarcoptiformes could be recovered from insect hosts but could not be collected from members of the order Trombidiformes. In the order Mesostigmata 13 species and in the order Sarcoptiformes 15 species were represented by the deutonymphal stage (Fig. 1.27). Among the Sarcoptiformes members, majority of the species showing insect association was known from species included under the family Acaridae. The deutonymphal stage of seven species could be collected from the family Acaridae and which included *A.solimani*, *R. vicantus*, *A.tariqi*, *S. boharti*, *Schweibea* sp., *C. manuri* and *C. subterraneousi*. Of these, all the membersexcept *S. boharti* showed association with termites like *O. obesus*, *O. feae* and *N. gardneri*. The family Histiotomatidae was found represented solely by their deutonymphal stages alone. The histiotomatid mites like *H. maritimus*, *H. sammari*, *H. furrowa* sp. nov. and *C. keralensis* sp. nov. were found associated with the insect hosts of the order Coleoptera while a single species, *H. herbali* was found associated with the termite, *O. obesus*. The families like Hemisarcoptidae, Winterschmidtidae and Suidasiidae were represented by single species, all of them in their deutonymphal stages alone. The species obtained were *C. glossinae* associated with *H. vigintioctopunctata*, *Procalvolia* sp. associated with *A. foviecollis* and *Sapracarus* sp. associated with *N. gardneri*from the families Hemisarcoptidae, Winterschmidtidae and Suidasiidae respectively. In the order Mesostigmata, the family Uropodidae included the higher number of species exhibiting insect association through deutonymphal stage. The deutonymphs of four species belonging to the family Uropodidae, viz. *U. heliocopridis*, *U. orbicularis*, *U. shangaica*and *C. almerodai* were found associated with coleopteran pests like *O. rhinoceros*, *B. rufomaculata*, *X. globosa* and *R. ferrugineus* respectively. Three species could be reported under the family Dinychidae based on their deutonymphal stage and they were *U. assamomarginata*, *U. javae* and *U. phoenicicola*, all of which were associated with the insect order Coleoptera. The

deutonymphal stage of two species viz. *Laelaps* sp. and *Dinogamasus* sp. could be reported under the family Laelapidae, both of which exhibited association with the order Coleoptera. The families like Parasitidae, Digamasellidae and Eviphididae were represented by a single species each, based on their deutonymphal stage alone, and the species included *Poecilochirus* sp., *D. quadrisetus* and *Alliphis* sp., all associated with the order Coleoptera.

Six species of mites associated with insect hosts were found represented by their adult males and which were *S. rhinocera* sp. nov. (Family: Diplogyniidae) associated with *O. rhinoceros*, *H. stramenti* (Family: Parasitidae) associated with *C. repertus*, phytoseiid members like *N. mapuche*, *A. largoensis*, *T. kroeffis* associated with *O. hyla* and *L. (L.) moolamkudensis* sp. nov. (Blattisociidae) associated with *B. tabaci*.

In the present study, life stages like the egg, larval, nymphal and adult stages of mites could be collected from five species viz. *L. chinensis* sp. nov. (Family: Podapolipidae) associated with *O. chinensis*, *P. palappuramensis* sp. nov. (Family: Podapolipidae) associated with *O. hyla*, *C. batocera* sp. nov. (Family: Canestriniidae) associated with *B. rufomaculata*, *A. oryctae* sp. nov. (Family: Canestriniidae) associated with *O. rhinoceros* and *T. Putrescentiae* (Family: Acaridae) associated with *O. rhinoceros*. There were only two species of mites in which only the larval stage showed association with insect hosts. The species included *Leptus treati* (Family: Erythaeidae) and *N. gratum* (Family: Trombidiidae) associated with *Oxya* spp. and *B. rufomaculata* respectively. It was also observed that a single species viz. *Digamasellus neodisetus* (Family: Digamasellidae) established association with its insect host, *O. rhinoceros* through its protonymphal stage.

The mites were found to exhibit different types of association with their insect hosts as shown in Table 1.8. The results of the study revealed that majority of mite species made use of their insect hosts as transport vehicle as 76% of the insect-mite association observed during the study could be designated as phoretic type (Fig. 1.28). It was also found that a single species of mite exhibited only a single type of association even though they showed distribution on different insect hosts. Majority of the phoretic species were proved to be the members of the order Mesostigmata, under which 27 species exhibited phoresy. Under Mesostigmata, the family Laelapidae contained the maximum number of phoretic species (Fig. 1.29), which

included five species viz. *Laelaps* sp., *H. heselhousi*, *H. sardous*, *H. subterranea* and *Dinogamasus* sp. phoretic on insects like *O. rhinoceros*, *R. ferrugineus* and dung beetle. Four species each were collected as phoretic members from the families Uropodidae, Dinychidae and Macrochelidae. The family Uropodidae was represented by phoretic mites like *U. heliocopridis*, *U. orbicularis*, *U. shangaica* and *C. almerodai* collected from insect hosts like *O. rhinoceros*, *B. rufomaculata*, *X. globosa* and *R. ferrugineus* respectively. The four species of phoretic mites belonging to the family Dinychidae could be listed as *U. assamomarginata*, *U. javae*, *U. phoenicicola* and *U. pilosetosa* collected from *R. ferrugineus* and *O. philemon*. The phoronts recovered under the family Macrochelidae were *M. krantzi*, *M. glaber*, *M. muscaedomesticae* and *M. perglaber*, collected from coleopteran pests like *O. longicollis*, *C. sordidus*, *R. ferrugineus* and dung beetle.

The families viz. Diplogyniidae, Parasitidae, Digamasellidae and Eviphididae were represented by two phoretic species each (Fig. 1. 29). The phoretic members, *S. rhinocera* sp. nov. and *T. rhynchophora* sp. nov. belonging to the family Diplogyniidae were collected from insect hosts viz. *O. rhinoceros*, *R. ferrugineus* respectively. The family Parasitidae was found represented by two species of phoronts, viz. *H. stramenti* and *Poecilochirus* sp. collected from dung beetle and *O. rhinoceros*. The species like *D. neodisetus* and *D. quadrisetus* belonging to the family Digamasellidae could be collected from insect hosts viz. *O. rhinoceros* and *R. ferrugineus*. The phoretic members recovered under the family Eviphididae were *A. halleri* and *Alliphis* sp. collected from *M. leda ismene* and *C. molossus*. The remaining families included under the order Mesostigmata, were Phytoseiidae and Blattisociidae and which were represented by a single species each viz. *N. mapuche* and *L. confusus* collected from *O. hyla* and *O. rhinoceros* respectively.

The order Sarcoptiformes reached the second position in terms of the numerical density of phoretic mites associated with insects (Fig. 1.29). The order was represented by 15 species grouped under four families viz. Histiostomatidae, Hemisarcoptidae, Winterschmidtidae, Acaridae and Suidasiidae. Majority of the species were members of the family Acaridae, which seven phoretic species like *A. solimani*, *R. vicantus*, *A. tariqi*, *S. boharti*, *Schweibea* sp., *C. manuri* and *C. subterraneousi*, of which six were found phoretic on termites like *N. gardneri*, *O. obesus* and *O. feae* and the remaining one on *O. rhinoceros*. The family

Histiostomatidae included five species of phoronts viz. *H. herbali*, *H. maritimus*, *H. sammari*, *H. furrowa* sp. nov. and *C. keralensis* sp. nov. collected from insects viz. *O. obesus*, *H. vigintioctopunctata*, *O. rhinoceros*, *A. foveicollis*, *A. frontalis* and *R. ferrugineus*. The families like Hemisarcoptidae, Winterschmidtidae and Suidasiidae were represented by a single species each viz. *C. glossinae* collected from *H. vigintioctopunctata*, *Procalvolia* sp. collected from *A. foveicollis* and *Sapracarus* sp. collected from *N. gardneri*.

The order Trombidiformes showed the lowest number of phoretic mites, with a total of seven species. All the families were represented by two or single species. The family Tarsocheylidae contained two species of phoronts viz. *H. longispinus* and *H. zanzibarensis* collected from *Gonocephalus* sp. and dung beetle. The family Dolichocybidae was represented by *P. foliata* and *P. indicus* sp. nov. The families like Cheyletidae, Microdispidae and Tarsonemidae were represented by *C. kuznetsovi*, *P. paramaevi* and *S. brasiliensis* collected from insect hosts viz. *Gonocephalus* sp., *O. feae* and *O. hyla* respectively.

The study also revealed that 13% of the mite associates of insects was predatory. Nine species of predatory mites belonging to families like Phytoseiidae, Blattisociidae and Cunaxidae of the order Mesostigmata showed association with the Hemipterans, *B. tabaci* and *A. floccosus*. The family Phytoseiidae had the major representation, by revealing six species viz. *A. channabasavannai*, *A. largoensis*, *A. vasiformis*, *E. ovalis*, *E. finlandicus* and *T. kroeffis*. The family Cunaxidae was found represented by species like *C. anomala* and *C. heterostriata*. A single novel species, *L. (L.) moolamkudensis* sp. nov. represented the family Blattisociidae. 10% of the insect associated mites were found to be ectoparasitic (Fig. 1.28). The study revealed that four species belonging to the order Trombidiformes and two species of the order Sarcoptiformes displayed ectoparasitic association. The order Trombidiformes was represented by the families viz. Podapolipidae, Erythaeidae and Trombidiidae. Of these, the family Podapolipidae was found represented by *L. chinensis* sp. nov. and *P. palappuramensis* sp. nov. parasitic on *O. chinensis* and *O. hyla*. The study revealed the ectoparasitic association of two species of mites, viz. *L. treati* and *N. gratum*, of which the former was found parasitizing two species of orthopteran pests like *O. hyla* and *O. chinensis* while the latter was parasitic on the coleopteran pest, *B. rufomaculata*. Two species belonging to the family Canestriniidae of the order

Sarcoptiformes viz. *C. batocera* sp. nov. and *A. oryctae* sp. nov. were found ectoparasitic on the beetle pests, *B. rufomaculata* and *O. rhinoceros* respectively. An in depth examination of the phoretic relationship between *O. longocollis* and its phoretic mite, *H. furrowa* sp. nov. revealed that the relationship extended beyond phoresy to develop into facultative necromeny.

A closer observation of the various taxa of mites revealed that the members of the order Mesostigmata exhibited only phoretic and predatory types of association with their insect hosts whereas the members of the order Sarcoptiformes displayed three types of association viz. phoresy, necromeny and parasitism (Fig. 1.30). Members of the order Sarcoptiformes exhibited versatile types of associations with their insect hosts, which could be designated as phoresy, ectoparasitism and necromeny. The family Acaridae of the order Sarcoptiformes reached the foremost position in accommodating the maximum number of phoretic species, followed by the families like Histiostomatidae (Order: Sarcoptiformes) and Laelapidae (Order: Mesostigmata). The majority of predatory acarines were found restricted to the order Mesostigmata, belonging to the families Phytoseiidae and Blattisociidae. The predatory mites assigned to the order Trombiformes were the members of the family Cunaxidae. Among the five species of parasitic mites, three were included under the order Sarcoptiformes and the remaining two belonged to the order Trombidiformes. The ectoparasitic mites were found restricted to the order Trombidiformes while the necromenic association was restricted to the order Sarcoptiformes.

The observations made on the acarine associates of the various species of insects enabled to encounter the maximum number of phoretic mite associations in coleopteran insects. Out of the total 52 cases of insect-mite associations recorded in the order Coleoptera, 47 could be designated as phoretic, four were ectoparasitic (Fig. 1.31) and the remaining one association was necromenic in nature. All the 10 different associations observed in the order Hemiptera were recognized to be predatory in nature. The 11 species of acarine associates with the order Blattodea were found to be phoretic. Of the total types of insect-mite associations identified in the order Orthoptera, two were found to be phoretic in nature while the remaining four were ectoparasitic in nature. A single type of association was noted between mites and Lepidopteran insects and which could be designated as phoretic.

D. Distribution pattern of mite associates on the body of insect hosts and the means of their attachment

Different species of mite associates showed variation in their preference to occupy the specific body parts of the insects. The different regions of the body of insect hosts preferred by the various species of mites were presented in Table 1.9. Some of the mite species showed preference to more than one body part of host insects. The larval forms of *L. treati* associated with the orthopteran pests like *O. hyla* and *O. chinensis* were found to get frequently attached to the thorax and femur of the host insects by means of their mouthparts while the parasitic mites on the above hosts, viz. *P. palappuramensis* sp. nov. and *L. chinensis* sp. nov. exhibited preference to get attached to the hindwings and abdomen. The adult female of *P. palappuramensis* sp. nov. was found to establish attachment using its mouthpart. The phoretic species like *N. mapuche* and *S. brasiliensis* were found attached on the hindwings of *O. hyla*. The deutonymphal stages of phoretic mites like *R. vicantus*, *Schweibea* sp., *C. subterraneousi*, *S. boharti*, *A. solimani*, *A. tariqi*, *C. manuri* and *Sapracarus* sp. collected from the three species of termites like *O. obesus*, *O. feae* and *N. gardneri* were found frequently adhered to the head capsule by means of their anal suckers. The predatory mites associated with the Hemipteran pests like *A. floccosus* and *B. tabaci* were not found attached to the body parts of the insect hosts, but instead were seen on the leaf surface where the whiteflies were found distributed.

The deutonymphal stages of species like *H. maritimus*, *H. sammari* and *Procalvolia* sp. associated with chrysomelid pests like *Altica* sp., *A. foveicollis*, *A. frontalis* and *H. unicolor* were mostly found restricted to the hypomeron and mesoventrite regions of the body of their host insects. The phoretic deutonymphal stages of *H. maritimus* and *C. glossinae* associated with *H. vigintioctopunctata* were found attached to the hypomeron and dorsal surface of abdomen respectively of the body of their insect host. All the above species of mite associates were found to establish attachment with their insect hosts using their anal suckers. Parasitic species like *A. oryctae* sp. nov. and *C. batocera* sp. nov. associated with beetle hosts viz. *O. rhinoceros* and *B. rufomaculata* were found to prefer the hindwings, subelytra and abdomen of their respective host insects. The larval stage of *N. gratum* was found attached to the stigmata of its host, *B. rufomaculata* using its mouthpart while the deutonymphal stage of *U. orbicularis* showed preference to occupy the under surface of the elytra of

its host. The latter was found attached by means of its anal pedicel. The deutonymphs of *H. furrowa* sp. nov. showed association with two insect hosts viz. *O. longicollis* and *C. sordidus* and it was found attached to different body regions of both species of insect hosts using its anal pedicel. On the host, *O. longicollis*, the deutonymphs showed preference to attach body parts like subelytra, hindwings, ventral surface, anterior part of mesosternum etc. while on *C. sordidus*, the deutonymphs preferred to occupy body parts like prosternum, meso and metaventrites. The mite species, *C. kuznetsovi* showed distribution exclusively on the hypomeron of the host insect, *Gonocephalus* sp. 1. The species was found attached to the host body by means of agglue like secretion. The adult individuals of *H. longispinus* were found attached to the abdomen of the host insect, *Gonocephalus* sp. 2. The different species of phoretic mites on the adult beetles of *O. rhinoceros* showed preference to occupy different body parts while those on the larvae showed no specific preference to any body part. The deutonymphal stages of *Histiostoma* sp. and *S. boharti* showed preference to get attached to the hypomeron of the insect host using their anal suckers while the phoretic adult stages of species like *S. rhinocera* sp. nov., *H. sardous* and *L. confusus* preferred to occupy different body parts like mesoventrite, prosternum, hypomeron and abdomen. Two species of parasitic mites viz. *A. oryctae* sp. nov. and *T. putrescentiae* preferred body parts like hindwings, subelytra and abdomen of their insect hosts.

Majority of the phoretic deutonymphs associated with the weevil pest, *R. ferrugineus* could be assigned to the family Uropodidae, and they were found attached to the host body with the help of a specialized structure called anal pedicel. But the deutonymph of *D. quadrisetus* preferred to occupy subelytral surface. The adult stage of *T. rhynchophora* sp. nov. was found on the abdominal ventrite of *R. ferrugineus* while the rest of the adult stages showed no preference to any specific part of the host insect. The deutonymph of *U. shangaica* showed preference to occupy the abdomen of its insect host, *X. globosa*. Most of the phoronts associated with the different species of dung beetles showed no specific preference to any particular body region and were devoid of any attachment organs. The adult individuals of both species of *Hypoaspis* were found attached to the prosternum of dung beetles, *C. repertus* and *C. molossus* while *P. foliata* showed preference to occupy the dorsal surface of abdomen of the

insect host. The phoront, *A. halleri* was exclusively found to occupy the groove present at the undersurface of the proboscis of its lepidopteran host, *M. leda ismene*.

In the present study, 20% of the recovered mite species showed no preference to colonize a specific body part of the host insect. Of the various species of mites which showed preference to a particular body part(s) of their insect host, a major share of mites preferred the abdominal segments (Fig. 1.32) of their insect hosts. 17% of the mite species collected were recovered from the abdominal segments of their insect hosts while 13% of mites preferred the head region of insects. 10% of mites were collected from the hypomeron of the insect body. Hindwings and subelytra of the insects were preferred by 9% of the total collected species. The mesoventrite and metaventrite regions of the insect body were preferred by 8% of insects while 7% of mites preferred to colonize the leg segments of their insect hosts. Sternal segments like prosternum and mesosternum were found preferred by 6% of mite species. The lowest number of mites (1%) could be recovered from the thoracic segments of the insect hosts. Despite this, detailed investigation made to trace the phoretic load of mites on different body parts of selected species of insect hosts revealed a different result. The highest population density of mites could be traced on the abdominal segments where the mean number of mites could be recorded as 743 ± 11.24 (Fig. 1.33). This was followed by the subelytral region where the average number of mites was 469 ± 8.75 . The hindwings of the insect hosts harboured an average of 230 ± 9.86 mites while the meso and metaventrites showed an average number of 154 ± 6.22 mites. The prosternum and mesosternum were found to harbor an average of 105 ± 12.41 mites. The different leg segments harboured an average of 92 ± 2.26 mites. The mean number of mites recovered from the hypomeron of insect hosts was 63 ± 5.41 . The number of mite species found on the insect head was very high, however, the phoretic load on the head was low, ie, 33 ± 1.41 . The minimum number of mites was found on the thoracic segments and which could be recorded as two.

The results of the present study also disclosed that some of the species preferred to colonize more than one part of the body of their insect hosts. The mites exhibited significant variation in the site preference on different body parts of their respective insect hosts (Table 1.10). As presented in table 1.10, a significant difference could be observed in the site preference of the same species of mite which showed distribution at multiple sites on the body of the same insect host. Accordingly, the species *H.*

sardous phoretic on *O. rhinoceros* could be collected from three different body regions like the head, prosternum and hypomeron, out of which prosternum was the most preferred region, whereas the species, *A. oryctae* sp. nov. found parasitic on the same host exhibited more preference to the abdominal region than the hindwings and subelytra. The Uropodine mite species phoretic on *O. rhinoceros* showed preference to the threecoxal leg segments, out of which the procoxal base was the most preferred one while the phoretic uropodine mite on *R. ferrugineus* preferred different body parts, like antennae and coxal base, without showing any preference to the three coxal segments. The mite, *U. assamomarginata* exhibited more preference to the mesoventrite of *R. ferrugineus* than the metaventricle. The parasitic mite, *C. batocera* sp. nov. infesting the beetle host, *B. rufomaculata* showed preference to hindwings followed by subelytra and then hindwings. The histiostomatid mite, *H. sammari* exhibited preference to different body regions when present on two different hosts like *A. foveicollis* and *A. frontalis*. Majority (85%) of *H. sammari* could be recovered from the hypomeron of *A. foveicollis*, but the same species when present on *A. frontalis*, 54% of which were found to prefer the mesoventrite. Another species of *Histiostoma*, *H. furrowa* sp. nov. showed more preference to the mesosternal groove of its host, *O. longicollis* followed by the subelytral surface. But the same species, when present on another host, *C. sordidus*, showed preference to the prosternum. The ectoparasitic mites of orthopteran pests like *O. hyla* and *O. chinensis* harboured more than one body part of host insects. *L. treati* ectoparasitic on *O. hyla* and *O. chinensis* preferred the thoracic segments of the insect than the leg femur. The members of Podapolipidae viz. *L.chinensis* sp. nov. and *P.palappuramensis* sp. nov. ectoparasitic on *O. chinensis* and *O. hyla* were seen on the hindwings and abdomen of their respective hosts. Both of the above mite species exhibited more preference to the abdominal segments than the hindwings.

E. Other relevant parameters of mite infestation on different species of insect hosts

Various parameters related to mite infestation on insect hosts such as the percentage of occurrence (percentage of beetles which hosted mites), prevalence (proportion of insects that hosted the particular mite species (in %), mean intensity (mean number of mites per infested insect host) and population range of mite species on insect hosts have been presented in table 1.11. Observations made on the above parameters

revealed that 91.8% adult individuals of the banana weevil, *O. longicollis* exhibited natural infestation by mites, indicating the highest percentage of occurrence (Fig. 1.34). This was followed by insect hosts like *H. unicolor* and *B. rufomaculata* in which mite infestation could be encountered in 87.9% and 87.5% of adults respectively. More than 80% of the adults of coleopteran members like *R. ferrugineus*, *O. rhinoceros*, *A. frontalis*, *A. foveicollis* exhibited mite infestation. More than 70% of the adult stages of insects like *O. hyla*, *O. philemon*, *C. molossus*, *Gonocephalus* sp.1 showed mite infestation. More than 50% of the adults of some other species like *O. chinensis*, *O. feae*, *O. obesus*, *N. gardneri* and *C. repertus* harboured mites. Less than 50% of the adults of the remaining species of insects like *Altica* sp., *C. sordidus*, *Gonocephalus* sp. 2, *H. vigintioctopunctata*, *X. globosa*, *M. leda ismene* were found infested by different species of mites. Unlike the adult stages, egg stages often showed 100% infestation by mites as evident in the case of *O. rhinoceros*. However, the infestation was less in the larval stage of the red palm weevil, *R. ferrugineus*, where less than 50% of larvae showed mite infestation.

Results of the studies on the prevalence of various mite species on different insect hosts enabled to record 100% prevalence of *A. tariqi* on the eggs of *O. rhinoceros* (Table 1.11). Among the adult stages of insect hosts, highest prevalence was recorded on the coleopteran insect, *O. longicollis* with respect to the mite species, *H. furrowa* sp. nov. The lowest rate of prevalence was recorded on the orthopteran pest, *O. hyla* by the phytoseiid mite, *N. mapuche*. Among the insect hosts belonging to the order Blattodea, the highest prevalence was recorded for the mite, *R. vicantus* on the termite host, *O. feae* and the lowest prevalence was accounted for *P. paramaevi* on the same species of termite. The mean intensity of mite infestation was found to be 100 in different species like *C. batocera* sp. nov. on *B. rufomaculata*, *A. oryctae* sp. nov. on *O. rhinoceros*, *P. indicus* sp. nov. on *C. repertus* and *P. foliata* on *C. molossus*. The mite intensity was found to be very low, approaching <10 in associations between *L. treati* and its orthopteran hosts, *O. chinensis* and *L. chinensis* sp. nov., *O. hyla* with *L. treati*, *N. mapuche* and *S. brasiliensis*, all termite-mite associations, *Altica* sp. with *H. maritimus*, *Procalvolia* sp. with *A. foveicollis*, *M. muscaedomesticae* with *C. sordidus*, *Gonocephalus* sp. with *C. kuznetsovi*, *H. vigintioctopunctata* with *H. maritimus* and *C. glossinae*, *O. longicollis* with *M. muscaedomesticae*, *O. rhinoceros* adult with *H. sammari* and *T. putrescentiae*, all other mite associations, *O. philemon*

with *U. pilosetosa* and *M. glaber*, *C. repertus* with *H. stramenti*, *Poechilochirus* sp., *M. krantzi* and *H. subterranea*, *C. molossus* with *Alliphis* sp. and *H. heselhousi*, *M. leda ismene* with *A. halleri*.

The study also revealed that in all cases of predatory mite infestation on whiteflies like *B. tabaci* and *A. floccosus*, the mean intensity of mite infestation was recorded to be < 10 although the prevalence was high in many species (Table 1.12). The predatory mite species which showed the highest prevalence and mean intensity was *L. (L.) moolamkudensis* sp. nov.

F. Impact of phoretic mite load on selected species of insect hosts

The body weight of selected species of insect hosts viz. *O. longicollis*, *O. rhinoceros* and *R. ferrugineus* showed significant variation before and after the removal of mite associates from their body (Table 1.13). As shown in table 1.13, the mean body weight of *O. longicollis* before the removal of mites was 125.27 ± 3.99 while it was found reduced to 121.35 ± 4.02 , after the removal of mites from their body. In the case of *O. rhinoceros*, the average body weight of the beetle before the removal of mites was 1829.8 ± 19.21 and after the removal of mites, the body weight was found reduced to 1807.40 ± 19.57 . A similar observation was made in *R. ferrugineus* also in which the mean body weight of the beetle with mites was 1017.70 ± 29.21 and after removal of mites, the weight got reduced to 974.30 ± 27.48 . In all the three cases, a statistically significant reduction was recorded in the body weight of the insects without mites (tested using Wilcoxon Signed Ranks Test).

A positive correlation was found to exist between the body weight of all the three species of insects (before and after removing mites) and the number of phoretic mites carried by them. The correlation coefficient recorded for *O. longicollis* (Fig. 1.35), *O. rhinoceros* (Fig. 1.36) and *R. ferrugineus* (Fig. 1.37) were 0.996, 0.930 and 0.916 respectively. The correlation in all the above three cases was found significant at 0.01 level.

2. Laboratory rearing, elucidation of mite-host association and life cycle parameters of a phoretic species, *Histiostoma furrowa* sp. nov. exhibiting facultative necromeny on the pseudostem weevil, *Odoiporus longicollis*

During the present study deutonymphal stages of a phoretic species viz. *H. furrowa* sp.nov.on the banana weevil, *O. longicollis* were effectively raised in the laboratory on a variety of substrates, including the cut piece of banana pseudostem, paper discs soaked with yeast solution, and decapitated weevil carcass (Fig. 1.38). Upon rearing on the above three culture substrates, the deutonymphs of the above species were found successfully molted into tritonymphs and undergone progressive development. The deutonymphs molted into tritonymphs within 2-3 days when they were reared on the carcass of the weevil whereas the molting took 5-6 days when the deutonymphs were placed in yeast solution and pseudostem. Also, it was found that some of the deutonymphs continued to remain in that particular stage for more than a month under similar conditions. When the deutonymphs were placed in medium 4, i.e carcass placed on pseudostem, nearly half of them dislodged from the weevil to the pseudostem and resumed their development. The deutonymphs were found successfully moulted into the tritonymphal stage and progressed to the adult stage when reared on all of the above media. Tritonymphs reared with the beheaded beetle cadaver were found to feed on the juicy parts of the carcass until the juicy secretion was fully depleted. The various developmental stages of *H. furrowa* sp. nov. like the larva, protonymph, tritontonymphas well as the adults exhibited necromeny. The deutonymphs of the species were found awaiting till the weevil carcass assumed a juicy texture, before they got molted into the tritonymphal stage. On the other hand, moulting took place within 2-3 days in the case of deutonymphs which were placed on the dead weevil. In the other two cases, where the deutonymph was placed in the yeast solution as well as the pseudostem, the deutonymphal stage got moulted into the tritonymphal stage within 5-6 days. The carcass of the beheaded weevil was found fed by all the subsequent stages. When the mites were given carcass placed on the pseudostem, around half of them were found dislodged and resumed development on pseudostem.

The larval stage was found to attain the adult hood within 4 days. When suitable conditions were provided in the laboratory to support the development of larva, the heteromorphic deutonymphal stage was found skipped and instead, the protonymph

got directly molted into the tritonymph. When the individual deutonymphs were isolated under suitable conditions (in carcass of weevil), they developed into adults in about 3 days while it took more than 6 days to develop into adult when placed on the pseudostem. The average duration of the various developmental stages have been presented in table 1.14 and 1.15.

The process of molting was observed in detail in the various developmental instars of the species. In the deutoquiescent instar, moulting was found initiated by the appearance of a suture, at the dorsal anterior region. The suture was found extended further, by the movement of first two pairs of legs of the moulting individual and finally the tritonymph was found shruggled out of the moulting skin. The entire procedure was found completed within 2-3 minutes. In all other instars, the moulting suture was found extended dorso-ventrally. The minimum time took by the deutonymph in its quiescent phase was 24 hours but quite often, some of the individuals remained in quiescence for about one week, even under favourable conditions.

Mate guarding was observed in cultures when the tritonymphs entered into their quiescent phase. The male was found to climb over the body of the female quiescent tritonymph along the side of the latter and finally rested on its dorsum. The first pair of legs of the male were positioned between the first and second pairs of legs of the female whereas the third and fourth pairs of legs were found kept on the abdomen of female. It was observed that during mate guarding, more than two males (upto four) tried to rest on the immature female but fighting between the aggregated males was not observed. Towards the end of the female quiescence, the male tapped on the dorsal posterior side of the female, giving an impression that the male stimulated the molting process. The mating was found initiated as soon as the molting process took place, with the male gripping tightly on the body of the female. Mating lasted for 13–15 minutes and during which the female was found moving with the male on her back. The female tritonymphs kept in isolation were found to lay eggs and exhibited arrhenotoky (unfertilized female producing exclusively male progeny). The sex ratio was recorded to be 1:1. It was also observed that a single female mated with multiple males, a condition called polyandry.

Morphological description of life stages of *Histiostoma furrowa* sp. nov.**Egg:** (Fig. 1.39A)

Colour: Creamy colour

Diameter: 120-125

Spherical, smooth and translucent.

Larva: (Fig. 1.39 B & C)

Colour: Creamy -white

Measurements: Length: 130(125–136)

Width: 78(75–79)

Dorsum (Fig. 1.42 a): Dorsal surface with uneven punctation, distributed on the posterior hysterosomal shield. Dorsum indistinctly divided into propodosomal and hysterosomal shields. Propodosoma with four pairs of setae and hysterosoma with nine pairs of setae. Dorsal shield with cuticular projections which protrude from the surface, bearing setae. All dorsal setae filiform, arising from the cuticular projections.

Venter (Fig. 1.42 b): Epimeres I-III well developed and sclerotised, not fused medially. Claparede's organ in the form of an oval disc, present on the coxal field I. Coxal fields I and III with setae, *cxI* and *cxIII* respectively. Seta *l*₅ placed posterior to the anal opening.

Gnathosoma: as in female

Legs (Fig. 1.43): Legs I-III with well developed claws. Length of seta *eon* legs I and II, exceeding the tibial length. Leg chaetotaxy: Fe 1 (*vF*)-0-0, Ge 2 (*cG*, *mG*)-2(*cG*, *mG*)-0, Ti 2(*gT*, *hT*)-2(*gT*, *hT*)-1(*kT*), Ta 11(*ba*, *la*, *ra*, *f*, *e*, *s*, *d*, *p*, *u*, *v*, *q*)- 11(*ba*, *la*, *ra*, *f*, *e*, *s*, *d*, *p*, *u*, *v*, *q*)- 6(*f*, *p*, *q*, *d*, *s*, *r*). Leg solenidiotaxy: one σ each on genua I and II, one ϕ each on tibia I, II and III, one ω each on tarsi I and II and famulus ε on genu I.

Protonymph: (Fig. 1.39 D & E)

Colour: Creamy- white

Measurements: Length: 178(170–182),

Width: 125(120–127)

Dorsum (Fig. 1.44 a): Dorsal shield indistinctly divided into two separate shields viz. the propodosomal and hysterosomal shields. All dorsal setae filiform, lateral setae being longer than the dorsal setae. 14 pairs of propodosomal and hysterosomal setae arising from short cuticular projections on the dorsal surface, one pair of propodosomal setae on unsclerotised cuticle. The propodosomal seta *vi* not as above, the latter inserted on unsclerotised cuticle. Opisthosomal gland, *gla* placed near *d3*.

Venter (Fig. 1.44 b): Epimere I of both sides fused with each other to assume a V shape. Epimeres II, III and IV well developed and sclerotised but not fused medially. Coxal fields I and III with one seta each, *cxI* and *cxIII* respectively. Seta *l5* placed posterior to the anal opening. Claparede's organ in the form of an oval disc, present on the coxal field IV.

Gnathosoma: as in female

Legs (Fig. 1.45): Legs I-IV with well developed claws. Seta *e* on the tarsal apex of legs I and II longer than the tarsus. Leg chaetotaxy: Fe 1(*vF*)- 1(*vF*)- 0-0, Ge 2 (*mG*, *cG*)- 2 (*mG*, *cG*)-0-0, Ti 2 (*hT*, *gT*)-2 (*hT*, *gT*)-1(*kT*)-0, Ta 11(*p*, *u*, *v*, *s*, *q*, *f*, *ra*, *wa*, *la*, *ba*)- 11(*p*, *u*, *v*, *s*, *q*, *f*, *ra*, *wa*, *la*, *ba*)- 8 (*p*, *u*, *v*, *q*, *f*, *w*, *r*, *s*)-8 (*p*, *u*, *v*, *q*, *f*, *w*, *r*, *s*). Leg solenidiotaxy: one σ each on genua I and II, one ϕ each on tibia I-III, one $\omega 3$ each on tarsi I and II, $\omega 1$ on tibia I.

Deutonymph: Since deutonymphal stage was obtained as a phoretic stage on the host insect, *O. longicollis* the description of the deutonymphal stage was included along with the systematic descriptions of other mites (Fig. 1.40 E & F, Fig. 1.41 A-D)

Tritonymph: (Fig. 1.39 F & G)

Colour: Creamy- white

Measurements: Length: 190(185–192)

Width: 143(140–145)

Dorsum (Fig. 1.46 a): Dorsum with distinct hysterosomal shield. Propodosoma with subcapitular setae located on separate shield. All 15 pairs of dorsal setae filiform, each arising on cuticular projections of the dorsal shield. Opisthosomal lyrifissures two pairs, *im* and *ia* placed near seta *d1* and *sh* respectively.

Venter (Fig. 1.46 b): Epimeres I of both sides fused to assume a V shape medially. Epimeres II-III free and sclerotised. Coxal fields I and III with seta *cxI* and *cxIII* respectively. Seta *l5* arising from cuticular projection, similar to dorsal seta, placed

posterior to the anal opening. Claparede's organs two pairs, in the form of an oval ring present in the coxal field IV.

Gnathosoma: as in female

Legs (Fig. 1.47): Legs I- IV with well developed claws. Seta *e* on tarsi I and II longer than the tibia. Leg chaetotaxy: Tr 0-0-1(*sR*)-0, Fe 1(*vF*)- 1(*vF*)- 0- 0, Ge 2(*cG*, *mG*)- 2(*cG*, *mG*)- 1(*cG*)- 0, Ti 2(*hT*, *gT*)- 2 (*hT*, *gT*)- 1(*kT*)- 1(*kT*), Ta 10(*p*, *f*, *u*, *e*, *v*, *d*, *ra*, *la*, *wa*, *ba*)- 9(*f*, *u*, *e*, *v*, *d*, *ra*, *la*, *wa*, *ba*)-6 (*p*, *f*, *q*, *d*, *r*, *w*)- 6 (*p*, *f*, *q*, *d*, *r*, *w*). Leg solenidiotaxy: one σ each on genua I and II, one ϕ each on tibia I and II, ωI on tibia I, $\omega 3$ each on tarsi I, II and IV, $\omega 2$ on tarsus II.

Adult Female: (Fig. 1.40 A & B)

Colour: Creamy -white

Measurements: Length: 210(205–215)

Width: 125(120–128)

Dorsum (Fig. 1.48 a): Dorsal shield divided into separate podosomal and hysterosomal shields with 15 pairs of setae. All dorsal setae filiform and inserted on cuticular projections present on dorsal surface. Opisthosomal lyrifissures three pairs, viz. *ia*, *im*, *ip*, opisthosomal gland, *gla*. A pair of vestigial setal alveoli, *va* present between *d4* and *d5*. Posterior part of dorsum appears very broad in gravid females. Internal (*vi*) and external vertical setae (*ve*) filiform, positioned at the same level. Internal scapular seta (*sci*) shorter than external scapular seta (*sce*). Copulatory opening (*c.o*) dorsal, between setae *d4*. Bursa copulatrix with a small duct leading from it and dome shaped upper part.

Venter (Fig. 1.48 b): Epimeres I of both sides fused with each other to form a V shape. Epimeres II-IV well developed and fused to the respective posterior epimerites. Epimere III fused to the heavily sclerotised ring shaped anterior genital papillae, antero-laterally. Coxal fields I, III and IV with setae, *cxI*, *cxIII* and *cxIV* respectively. Claparede's organ one pair, in the form of an oval ring present in the coxal field IV. Seta *d6* arising on cuticular projection, similar to other dorsal setae. Anal seta *a4* placed lateral to the Claparede's organ and anterior to the anal opening.

Gnathosoma (Fig. 1.49 f): Gnathosoma visible. Pedipalps with a large palpal solenidion, ω longer than the eupathidial setae, *ul* and *ul'*. Subcapitulum with a filiform ventral solenidion (*m*). Chelicera flattened with long cheliceral setae.

Legs (Fig. 1.49): Legs I-IV end with well developed claws. Seta *d* on legs I and II long but not longer than the entire tarsus. Leg chaetotaxy: Tr 1(*pR*)- 1(*pR*)-1(*sR*)-0, Fe 1(*vF*)- 1(*vF*)- 0-1(*vF*), Ge 2(*mG*, *cG*)-2(*mG*, *cG*)-0-0, Ti 2(*hT*, *gT*)-2(*hT*, *gT*)-1(*kT*)-1(*kT*), Ta 13 (*p*, *q*, *u*, *v*, *wa*, *e*, *d*, *s*, *f*, *ra*, *la*, *ba*, *aa*)- Ta 11(*p*, *q*, *u*, *v*, *wa*, *e*, *d*, *f*, *ra*, *la*, *ba*)- Ta 10 (*p*, *u*, *v*, *q*, *e*, *s*, *f*, *r*, *w*, *d*)- Ta 10 (*p*, *u*, *v*, *q*, *e*, *s*, *f*, *r*, *w*, *d*). Leg solenidiotaxy: two σ on genu I, one σ on genu II, one ϕ each on tibia I-IV, one ω each on tarsi I and II, one ω_2 and ω_3 on tibia I and tarsus I respectively.

Adult Male: (Fig. 1.40 C & D)

Colour: Creamy- white

Measurements: Length: 275(270–285)

Width: 144(142–148)

Dorsum (Fig. 1.50 a): Dorsal chaetotaxy and opisthosomal fissures similar to those of the female, but the setal length differs from that of the female.

Venter (Fig. 1.50 b): Epimeres I of either sides fused medially to form Y shape. Epimeres I and II fused to form a sclerotised structure. Epimere III sclerotised and fused to epimere IV, the latter vestigial. Coxal fields I, III and IV with a pair of seta each. Claparede's organ two pairs, in the form of an oval ring present in the coxal field IV. Anal seta two pairs, inserted anterior and posterior to anal opening.

Gnathosoma: similar to female.

Legs (Fig. 1.51): Leg chaetotaxy and solenidiotaxy similar to that of the female.

2. Systematic position of mites associated with insects

Phylum	Arthropoda von Siebold, 1848
Subphylum	Chelicerata Heymons, 1901
Class	Arachnida Cuvier, 1812
Subclass	Acari Leach, 1817
I. Superorder	: Parasitiformes Reuter, 1909
A. Order	: Mesostigmata G. Canestrini, 1891
Suborder	: Trigynaspida Camin and Gorirossi, 1955
Cohort	: Antennophorina Berlese, 1892
i) Superfamily	: Celaenopsoidea Tragardh, 1950
a) Family	: Diplogyniidae Tragardh, 1950
1. Genus	: <i>Tridiplogynium</i> Tragardh, 1950
	1: <i>Tridiplogynium rhynchophora</i> sp. nov.
2. Genus	: <i>Schizodiplogynium</i> Tragardh, 1950
	2. <i>Schizodiplogynium rhinocera</i> sp. nov.
Suborder	: Monogynaspida Camin & Gorirossi, 1955
Cohort	: Uropodina Kramer, 1882
Subcohort	: Uropodidae Kramer, 1881
ii) Superfamily	: Uropodoidea Kramer, 1881
b) Family	: Uropodidae Kramer, 1881
3. Genus	: <i>Uropoda</i> Latreille, 1805
	3: <i>Uropoda heliocopridis</i> Oudemans, 1901
	4: <i>Uropoda orbicularis</i> Muller, 1776
	5: <i>Uropoda shangaica</i> Wisneiowski & Hirschmann, 1996
4. Genus	: <i>Centrouropoda</i> Berlese, 1917
	6. <i>Centrouropoda almerodai</i> Hiramatsu & Hirschmann, 1992
c) Family	: Dinychidae Berlese, 1916

5. Genus : *Uroobovella* Berlese, 1903
- 7: *Uroobovella assamomarginata* Hiramatsu & Hirschmann, 1979
- 8: *Uroobovella javae* Wisneiowski, 1981
- 9: *Uroobovella phoenicicola* Kontschan, Tambe and Riolo, 2012
- 10: *Uroobovella pilosetosa* Kontschan, 2012
- Cohort : Gamasina Kramer, 1881
- Subcohort : Parasitiae Reuter, 1909
- iii) Superfamily : Parasitoidea Oudemans, 1901
- d) Family : Parasitidae Oudemans, 1901
6. Genus : *Holoparasitus* Oudemans, 1936
- 11: *Holoparasitus stramenti* Karg, 1971
7. Genus : *Poechilochirus* G. & R. Canestrini, 1882
- 12: *Poechilochirus* sp.
- Subcohort : Dermanyssiae Evans & Till, 1979
- iv) Superfamily : Rhodacaroidea Oudemans, 1902
- e) Family : Digamasellidae Evans, 1957
8. Genus : *Digamasellus* Berlese, 1905
- 13: *Digamasellus neodisetus* Hurlbutt, 1967
- 14: *Digamasellus quadrisetus* (Berlese, 1921)
- v) Superfamily : Eviphidoidea Berlese, 1913
- f) Family : Eviphididae Berlese, 1913
9. Genus : *Alliphis* Halbert, 1923
- 15: *Alliphis halleri* (G. R. Canestrini, 1881)
- 16: *Alliphis* sp.
- g) Family : Macrochelidae Vitzthum, 1930
10. Genus : *Macrocheles* Latreille, 1829
- 17: *Macrocheles glaber* (Muller, 1860)

- 18: *Macrocheles krantzi* Evans & Hyatt, 1963
- 19: *Macrocheles muscaedomesticae* (Scopoli, 1772)
- 20: *Macrocheles perglaber* Filipponi & Pegazzano, 1962
- vi) Superfamily : Phytoseioidea Berlese, 1916
- h) Family : Phytoseiidae Berlese, 1916
11. Genus : *Amblyseius* Berlese, 1914
- 21: *Amblyseius channabasavannai* Gupta & Daniel, 1978
- 22: *Amblyseius largoensis* (Muma, 1955)
- 23: *Amblyseius vasiformis* Moraes & Mesa, 1991
12. Genus : *Neoseiulus* Hughes, 1948
- 24: *Neoseiulus mapuche* Ferragut & Navia, 2015
13. Genus : *Euseius* De Leon, 1967
- 25: *Euseius finlandicus* (Oudemans, 1915)
- 26: *Euseius ovalis* (Evans, 1953)
14. Genus : *Transeius* Chant & McMurtry, 2004
- 27: *Transeius kroeffis* Goncalves & Ferla, 2017
- i) Family : Blattisociidae Garman, 1948
15. Genus : *Lasioseius* Berlese, 1916
- 28: *Lasioseius confusus* Evans, 1958
- 29: *Lasioseius (Lasioseius) moolamkudensis* sp. nov.
- vii) Superfamily : Dermanyssoidea Kolenati, 1815
- j) Family : Laelapidae Berlese, 1892
16. Genus : *Laelaps* Koch, 1836
- 30: *Laelaps* sp.
17. Genus : *Hypoaspis* G. Canestrini, 1884
- 31: *Hypoaspis heselhousi* Oudemans, 1912
- 32: *Hypoaspis sardous* (Canestrini, 1884)

33: *Hypoaspis subterranean* Willman, 1952

18. Genus : *Dinogamasus* Kramer, 1898

34: *Dinogamasus* sp.

II. Superorder : Acariformes Zakhvatkin, 1952

B. Order : Trombidiformes Reuter, 1909

Suborder : Prostigmata Kramer, 1877

viii) Superfamily : Bdelloidea Duges, 1834

k) Family : Cunaxidae Thor, 1902

19. Genus : *Cunaxa* Von Heyden, 1826

35: *Cunaxa anomala* Khaustov & Kuznetsov, 1998

36: *Cunaxa heterostriata* Khaustov & Kuznetsov, 1998

ix) Superfamily : Erythraeoidea Grandjean, 1947

l) Family : Erythraeidae Oudemans, 1992

20. Genus : *Leptus* Latreille, 1795

37: *Leptus treati* Welbourn & Jennings, 1991

x) Superfamily : Trombidioidea Leach, 1815

m) Family : Trombidiidae Leach, 1815

21. Genus : *Neosilphitrombium* Fain, 1992

38: *Neosilphitrombium gratum* Fain, 1992

xi) Superfamily : Cheyletoidea Leach, 1815

n) Family : Cheyletidae Leach, 1815

Genus : *Cheyletus* Latreille, 1796

39: *Cheyletus kuznetsovi* Bochkov & Khaustov, 1999

Cohort : Heterostigmatina Berlese, 1899

xii) Superfamily : Tarsocheyloidea Atyeo & Baker, 1964

o) Family : Tarsocheylidae Berlese, 1904

22. Genus : *Hoplocheylus* Atyeo & Baker, 1964

40: *Hoplocheylus longispinus* Atyeo & Baker, 1964

41: *Hoplocheylus zanzibarensis* Khaustov & Ermilov, 2018

xiii) Superfamily : Dolichocyboidea Mahunka, 1970

p) Family : Dolichocybidae Mahunka, 1970

23. Genus : *Pavania* Lombardini, 1949

42: *Pavania foliata* Khaustov & Frolov, 2020

xiv) Superfamily : Pygmephoroidae Cross, 1965

q) Family : Microdispidae Cross, 1965

24. Genus : *Premicrodispus* Cross, 1965

43: *Premicrodispus paramaevi* Hosseini-Navah & Haji-qanbar, 2014

r) Family : Pygmephoridae Cross, 1965

25. Genus : *Pygmephorus* Cross & Moser, 1971

44. *Pygmephorus indicus* sp. nov.

xv) Superfamily : Tarsonemoidea Canestrini & Fanzago, 1877

s) Family : Tarsonemidae Kramer, 1877

26. Genus : *Steneotarsonemus* Beer, 1954

45. *Steneotarsonemus brasiliensis* Flechtmann, 1993

t) Family : Podapolipidae Ewing, 1922

27. Genus : *Podapolipus* Rovelli & Grassi, 1888

46: *Podapolipus palappuramensis* sp. nov.

28. Genus : *Locustacarus* Ewing, 1924

47: *Locustacarus chinensis* sp. nov.

C. Order : Sarcoptiformes Reuter, 1909

Suborder : Oribatida (Duges, 1833)

Cohort : Astigmatina Canestrini, 1891

xvi) Superfamily : Histiosomatoidea Berlese, 1897

u) Family : Histiosomatidae Berlese, 1897

29. Genus : *Histiostoma* Kramer, 1876
 48: *Histiostoma herballi* Eraky, 2017
 49: *Histiostoma maritimus* (Oudemans, 1914)
 50: *Histiostoma sammari* Eraky, 1999
 51. *Histiostoma furrowa* sp. nov.
30. Genus : *Curculanoetus* Fain, 1974
 52: *Curculanoetus keralensis* sp. nov.
- xvii) Superfamily : Canestriniodea Berlese, 1884
 v) Family : Canestriniidae Berlese, 1884
31. Genus : *Canestriniella* Berlese, 1910
 53: *Canestriniella batocera* sp. nov.
32. Genus : *Athogavia* Haitlinger, 1989
 54: *Athogavia oryctae* sp. nov.
- xviii) Superfamily : Hemisarcoptoidea Oudemans, 1908
 w) Family : Hemisarcoptidae Lignieres, 1893
33. Genus : *Congovidia* Fain &Elsen, 1971
 55: *Congovidia glossinae* Fain &Elsen, 1971
- x) Family : Winterschmidtidae Oudemans, 1923
34. Genus : *Procalvolia* Fain, 1971
 56. *Procalvolia* sp.
- xix) Superfamily : Acaroidea Latreille, 1802
 y) Family : Acaridae Latreille, 1802
35. Genus : *Acarus* Linnaeus, 1758
 57: *Acarus solimani* Eraky, 1999
36. Genus : *Rhizoglyphus* Claparede, 1869
 58: *Rhizoglyphus vicantus* Manson, 1977
37. Genus : *Acotyledon* Oudemans, 1903

59: *Acotyledon tariqi* Ashfaq *et al.*, Chaudhri, Sher & Aslam, 1987

38. Genus : *Sancassania* Oudemans, 1916

60: *Sancassania boharti* Cross, 1968

39. Genus : *Schweibea* Oudemans, 1916

61: *Schweibea* sp.

40. Genus : *Caloglyphus* Berlese, 1923

62: *Caloglyphus manuri* Eraky & Osman, 2008

63: *Caloglyphus subterraneousi* Fakeer, Eraky, Ahmad & Soliman, 2014

41. Genus : *Tyrophagus* Oudemans, 1924

64: *Tyrophagus putrescentiae* Schrank, 1781

z) Family : Suidasiidae Hughes, 1948

42. Genus : *Sapracarus* Fain & Philips, 1978

65: *Sapracarus* sp.

3. Taxonomic Description of insect associated mites collected during the study

Results of the survey carried out during the study on the mite associates of agriculturally important insects revealed the association of 65 species of mites belonging to 42 genera, 26 families and three orders. The present part of the thesis deals with the taxonomic description of mites mounted on a research microscope (LabovisionSense i4000). The measurements of the various species were taken using the software Zeiss blue available with the microscope (Zeiss Scope AX1) and presented in μm . Detailed description of each species has been present below along with the details of their classification.

Superorder : Parasitiformes Reuter, 1909

Order : Mesostigmata G. Canestrini, 1891

Suborder : Trigynaspida Camin and Gorirossi, 1955

Cohort : Antennophorina Berlese, 1892

Superfamily : Celaenopsoidea Tragardh, 1950

Family : Diplogyniidae Tragardh, 1950

Genus : *Tridiplogynium* Tragardh, 1950

Generic diagnosis: Lateral shields with three pairs of setae, metasternal shield narrow but distinct. Ventri- anal shield triangular and projects posteriorly where it is continuous with the posterior ends of ventral and marginal shields. Peritreme long and extending beyond coxa I, stigmata near the middle of coxa IV.

***Tridiplogynium rhynchophora* sp. nov.**

(Fig.1.52 – 1.53)

Colour: Dark brown

Measurements: Length: 1083(1075–1090)

Width: 736 (730–748)

Description

Adult female

Dorsum (Fig. 1.52 a, 1.58): Dorsal shield broad anteriorly and pointed towards the posterior end, bearing 35 pairs of setae. Setae *j1*, *j3*, *j5*, *z5*, *s4*, *s7*, *s9*, *J5*, *Z1*, *Z5*, *S1*, *S2*, *S3*, *S4*, *S5* longer than the corresponding setae in the series and barbed distally. All other setae very short, smooth and pointed. Idiosomal setal pattern: 20A (Propodosomal): 15B (Hysterosomal). Length of setae: *j1* 136 (125–143), *j3* 143 (142–156), *j4* 41 (40–43), *j5* 108 (107–112), *z1* 35 (33–36), *z2* 39 (36–38), *z5* 114 (112–117), *s1* 42 (41–44), *s2* 41 (40–43), *s3* 42 (41–42), *s4* 201 (198–203), *s5* 42 (40–44), *s6* 41 (40–42), *s7* 177 (175–183), *s8* 43 (41–44), *s9* 183 (180–186), *r3* 43 (41–45), *r4* 42 (41–44), *r5* 42 (40–43), *r6* 43 (42–44), *J5* 115 (112–116), *Z1* 117 (115–119), *Z5* 186 (182–188), *S1* 108 (106–110), *S2* 104 (102–108), *S3* 102 (102–105), *S4* 374 (371–376), *S5* 103 (103–107), *R1* 62 (61–64), *R2* 64 (63–65), *R4* 63 (62–64), *R5* 62 (63–65).

Venter (Fig. 1.52 b): Tritosternum with pilose lacinia fused throughout the length. Anterior border of sternal shield concave while the posterior part incised medially. Three pairs of setae *st1*, *st2* and *st3* located on the sternal shield. Metasternal shield narrow, distinct and without any setae. Lateral shields triangular, bearing three pairs of setae (*lt1*, *lt2* and *lt3*). Mesogynal shield narrow, placed posterior to lateral shield. Setae *st1* long and pilose 68 (68–71), *st2* 34 (33–37), *st3* 12 (10–13), *lt1* 93 (91–96), *lt2* 36 (32–37), *lt3* 95 (94–97). Endopodal elements distinct. Vaginal sclerites claviform, stalk widening gradually towards the oval head. Ventrianal shield with six pairs of setae; *JV1* 81 (78–83), *JV2* 68 (66–68), *JV3* 78 (76–79), *JV4* 88 (86–89), *JV5* 68 (66–69), *ZV1* 69 (68–73). Marginal shield with one pair of setae, *ZV2* 120 (119–124). Peritreme extending beyond coxa I, stigmata placed at the middle of coxa IV.

Gnathosoma (Fig. 1.53 c, d, e): Tectum pointed with even edges and concave sides. Subcapitulum with four pairs of setae, one pilose and the rest smooth. Fixed digit of chelicerae with 12 teeth and movable digit with seven teeth, fringed appendage placed lateral to the movable digit.

Leg (Fig. 1.53 b): Genu of leg IV with five barbed and one smooth setae.

Male: Not found while sampling

Materials examined: Holotype: Adult ♀, collected from *R.ferrugineus* at Moolamkudam region (10°23'19.8"N 76°19'33.4"E) of Thrissur Dt., Kerala, India, on 23.06.2018, Coll. Anjitha K Bhadran.

Paratypes: 3 ♀♀, collection details same as that of the holotype.

Type deposition: All type specimens are presently deposited in the Division of Acarology, Department of Zoology, University of Calicut. The holotype will be transferred to the Zoological Survey of India, Calicut after publication.

Etymology: The specific epithet '*rhynchophora*' is derived from the name of host insect *R. ferrugineus* from which the species was collected.

Remarks: The present species possesses all characters unique to the genus *Tridiplogynium* and hence assigned to the above taxon. The genus presently includes three species viz. *T. inexpectatum* Tragardh 1950 collected from the beetle *Veturius transverses*, South America, *T. munizi* Machado-Allison 1964 and *T. scorzai* Machado-Allison & Esquivel, 1966 and the present new species forms the fourth addition to the genus. This is the first record of the genus from the insect host, *R. ferrugineus*.

The new species resembles the type species, *T. inexpectatum* in general morphology, but stands clearly distinct from the above species in the presence of several unique features, which could be listed as : (1) Dorsal shield with 35 pairs of setae (41 in *T. inexpectatum*); (2) some of the dorsal setae long and pilose (all dorsal setae short and smooth in *T. inexpectatum*); (3) setae on the sternal shield, *st1*, *st4* and *st5* distally pilose (smooth in *T. inexpectatum*) and (4) subcapitulum with one pair of pilose setae (all subcapitular setae smooth in *T. inexpectatum*). Based on the above features, the present species is given the status of a new species, assigned to the genus *Tridiplogynium* thereby representing the fourth species of the genus as well as a new host record.

Genus: *Schizodiplogynium* Tragardh, 1950

Generic diagnosis: Dorsal shield with numerous long hairs. The posterior margin of sternal shield deeply incised, lateral shields triangular. Metasternal shield narrow, mesogynal shield present. Mandible with numerous strong teeth.

***Schizodiplogynium rhinocera* sp. nov.**

(Fig. 1.54 - 1.57)

Colour: Tan

Measurements: Length: 553 (550–560)

Width: 395 (385–397)

Description**Female:**

Dorsum (Fig. 1.54, 1.58, 1.59): Length: 550–560 μm , width: 385–397 μm . Dorsal shield lightly reticulated with 32 pairs of setae, seta *j1* single, not paired, all smooth and pointed. Length of setae: *j1* 25 (22–25), *j2* 21(20–22), *j3* 18(16–19), *j4* 19(19–21), *j5* 19 (19–20), *z2* 23 (22–25), *z3* 21 (20–23), *z4* 20 (19–22), *z5* 20(20–23), *s3* 22 (21–23), *s4* 21(20–23), *s5* 19(19–22), *r2* 19(18–21), *r3* 20 (19–22), *r4* 19 (19–20), *r5* 20(19–21), *J1* 12(12–14), *J2* 12(11–13), *J3* 13(12–13), *J4* 13(13–15), *J5* 19 (18–21), *Z1* 24(22–25), *Z3* 24(23–25), *Z4* 27(25–30), *S1* 24(22–25), *S2* 25(24–25), *S3* 27(25–28), *R1* 23(21–24), *R2* 24(22–25), *R3* 23(22–25), *R4* 25(23–25), *R5* 25(23–26).

Venter (Fig. 1.55a): Tritosternum with pilose lacinia fused throughout the length. Sternal shield concave anteriorly, with the posterior part incised medially. Three pairs of setae (*st1*, *st2* and *st3*) located on the sternal shield (Fig. 1.57 a). Metasternal shield not discernible. Lateral shields triangular so that on lying close together almost form a square, and with two pairs of setae (*lt1* and *lt2*). Mesogynal shields rectangular, located between the lateral shields. Setae *st1* long and pilose, measuring 42(40–44), *st2* 21(20–23), *st3* 44(40–45), *st4* 21 (20–23), *st5* 21 (20–22). Endopodal elements distinct. Vaginal sclerites widening anteriorly and with a stalk posteriorly. Ventrianal shield with six pairs of setae; *JV1* 22(21–23), *JV2* 21(20–23), *JV3* 23(21–24), *JV4* 23(22–25), *ZV1* 21(20–23), *ZV2* 22(22–25). Marginal shield with one pair of setae, *R6*. Peritreme extending beyond coxa I, stigmata located between coxae III and IV. Eight pores arranged in a line, lateral to the peritreme, at the level of coxa II.

Male (Fig. 1.55b): The dorsal shield with the same length and chaetotaxy as that of the female. The venter with a large holovenal shield, bearing 11 pairs of setae.

Gnathosoma (Fig. 1.56): Tectum (Fig. 1.56 a) with a sharp median mucro and lateral concave sides. The middle portion of the tectum with transverse lines placed between latitudinal lines. The subcapitulum (Fig. 1.56 b) with four pairs of setae, three smooth and pointed, one barbed. Fixed digit of chelicerae with nine teeth, movable digit with seven teeth. The lateral side of movable digit of chelicera with three fringed and one smooth appendage (Fig. 1.57 b).

Leg (Fig. 1.57 c): Leg I without ambulacrum. Genu of leg IV with 6 smooth setae and two barbed setae.

Materials examined: Holotype: Adult ♀ collected from *O. rhinoceros* at the Moolamkudam region (10°23'19.8"N 76°19'33.4"E) of Thrissur Dt., Kerala, India on 15.05.2018, Coll. Anjitha K Bhadrán.

Paratypes: 3 ♀♀ and 2 ♂♂ collected from the type locality of the holotype.

Type deposition: All type specimens are presently deposited in the Division of Acarology, Dept. of Zoology, University of Calicut. The holotype will be transferred to the Zoological Survey of India, Calicut after publication.

Etymology: The specific epithet '*rhinocera*' is derived from the name of the insect host, '*O. rhinoceros*' from which the present species was collected.

Remarks: The genus *Schizodiplogynium* (Tragardh, 1950) was erected based on the type species, *S. capillatum*, described by Tragardh, 1950 collected from passalid beetle, *Ephisphenus moorei*, Ceylon. The species is characterized by presence of numerous long setae on the dorsal shield. The present species possesses all the features characterisitic to the genus *Schizodiplogynium*, with the exception of the numerous long dorsal setae, characterisitic to the type species. Presently, the includes two species viz. the type species, *S. capillatum* and the Indian species, *S. indicum* described by Bhattacharya (1971) collected from rotten straw. The present species differs from the type species, *S. capillatum* in shorter length of dorsal shield setae, chaetotaxy of dorsal and ventral shields and the presence of long barbed setae on genu IV. The present species greatly resembles the Indian species, *S. indicum* in several respects such as the possession of reticulated dorsal shield, triangular lateral shields, rectangular mesogynial shield, indistinct metasternal shield, peritrematal pores, multidentate fixed and movable digits on chelicerae. However, the following characters present in the present specimens distinguish it from *S. indicum*, and which

could be listed as: (1) Body length of 550–560 and width of 385–397 in *S.rhinocerasp.nov.* (length 603–648 and width 414–459 in *S. indicum*); (2) all dorsal setae short and stout in *S.rhinocera sp.nov.* (two pairs of long dorsal setae in *S. indicum*); (3) dorsal shield with 32 pairs of setae and one unpaired setae (dorsal shield with 37 pairs of setae in *S. indicum*); (4) gnathotectum with smooth concave sides lateral to mucro and median longitudinal striated ornamentation below the mucro (gnathotectum with serrated concave sides lateral to mucro in *S. indicum*, no ornamentations below mucro) and (5) chelicerae of female with three fringed and one smooth appendage (chelicerae of female with two fringed and one smooth). This forms the first report of the genus from the insect host, *O. rhinoceros*.

Suborder : Monogynaspida Camin and Gorirossi, 1955

Cohort : Uropodina Kramer, 1882

Subcohort : Uropodiae Kramer, 1881

Superfamily : Uropodoidea Kramer, 1881

Family : Uropodidae Kramer, 1881

Genus : *Uropoda* Latreille, 1805

Generic diagnosis: Hypostomal setae smooth and needle like. Horn shaped corniculi and denticulated lacinia. Epistome narrow and lancet shaped. Chelicera without nodus with variously shaped hyaline appendage. Anterior part of fixed digit usually dentate while movable digit with sharp end.

***Uropoda heliocopridis* (Oudemans, 1901)**

(Fig. 1.60)

Colour: Brown

Measurements: Length: 314–318

Width: 215–220

Description**Deutonymph:**

Dorsum (Fig. 1.60 a): Dorsum ovoid with a triangular rostrum. Dorsal surface ornamented with punctations. Dorsum with 32 pairs of short and pointed setae, 18 distributed on podosoma and 14 distributed on opisthosoma, all of the same size.

Venter (Fig. 1.60 b): Sternal shield long, extending from the level of coxa I to coxa IV, with a straight posterior margin, ornamented with small, strong pore like structures. Ventral shield originating adjacent to the sternal shield, and bears four pairs of setiform setae. Anal shield circular, with two pairs of anal setae. Peritreme extends to the level of seta *s*₂, stigmata between coxae II and III.

Gnathosoma: Chelicera with well developed fixed and movable digits each with two and five teeth respectively.

Legs: Legs I-IV with well developed ambulacra. All legs with needle like setae.

Adult: Not recovered during sampling.

Materials examined: 4 deutonymphs collected from *O. rhinoceros* at the Moolamkudam region (10°23'19.8"N 76°19'33.4"E) of Thrissur Dt., Kerala, India on 21.05.2017; 3 deutonymphs from *O. rhinoceros* collected at Killikavu (10°45'43.5"N 76°19'21.5"E), Palakkad Dt., Kerala, India on 26.11.2018, Coll. Anjitha K Bhadrán.

Host range: *Coprini* sp.

Remarks: The present specimens show great morphological similarity to *U. heliocopridis* (Oudemans, 1901) and hence fixed so. This forms the first report of the species from *O. rhinoceros*.

***Uropoda orbicularis* Muller, 1776**

(Fig. 1.61)

Colour: Brown

Measurements: Length: 480–510

Width: 175–180

Description**Deutonymph:**

Dorsum (Fig. 1.61 a): Idiosoma oval with an anteriorly pointed rostrum, and widening towards the posterior end. No sculptural pattern on the dorsal shield. Dorsal setae 57 pairs, of which 30 pairs originating at the anterior part of idiosoma while the remaining 27 pairs on opisthocoma. All dorsal setae smooth and needle like. Lateral shield narrow, with 10 pairs of setae.

Venter (Fig. 1.61 b): Sternum short and punctated, extending between coxae II and IV. Sternal setae 8 pairs, all short and needle like. Sternal setae, *st1* placed on anterior margin of sternal shield, *st2* at the middle of coxa II, *st3* anterior to coxa III, *st4* on level of anterior margin of coxa III, *st5* at the level of middle of coxa III, *st6* posterior to coxa III, *st7* anterior to coxa IV and *st8* at the middle of coxa IV. Ventrianal shield without any ornamentation and with smooth and needle like setae. Adanal setae smooth and needle like, postanal setae larger among all the setae on the shield.

Gnathosoma: Fixed and movable digits of chelicerae bear one tooth each, fixed digit longer than the movable digit and multidentate. Corniculi horn like.

Legs: Legs I-IV bear simple setae. All legs with well developed ambulacra. Leg I with elongated ambulacrum.

Adult: Not recovered during sampling.

Materials examined: 7 deutonymphs, collected from *B. rufomaculata* at Moolamkudam region (10°23'19.8"N 76°19'33.4"E) of Thrissur Dt., Kerala, India, on 12.08.2021, Coll. Anjitha K Bhadrán.

Host range: *R. ferrugineus*, coprophagous beetles.

Remarks: The specimens examined during the study show morphological similarity to *U. orbicularis* Muller, 1776. This forms the first report of the species from *B. rufomaculata*.

***Uropoda shangaica* Wisneiowski & Hirschmann, 1996**

(Fig. 1.62)

Colour: Tan

Measurements: Length: 520–550

Width: 395–410

Description

Deutonymph:

Dorsum (Fig. 1.62 a): Dorsal shield oval and punctated, punctations being clearly distinct along the lateral margins. 32 pairs of short and spine like dorsal setae present, 16 on podosoma and 16 on opisthosoma. Distinct circular ornamentation between setae *j6* and *J1*.

Venter (Fig. 1.62 b): Ventral shield distinct from anal shields, with four pairs of setae. Sternal shield located very close to the sub-rectangular ventral shield. Sternal shield with five pairs of simple and pointed setae. Short and simple setae present at the lateral body margin, starting from the level of *st2* and extending to the level of anal opening. Peritreme extending to the level of *s2*, stigmata reaching the posterior coxa II.

Gnathosoma: Fixed and movable digits of chelicerae well developed, teeth not distinct.

Legs: Legs I-IV bear needle like setae. All legs with well developed ambulacra.

Adult: Not recovered during sampling.

Materials examined: 6 deutonymphs collected from *X. globosa* at the Calicut University Campus (11°08'01.9"N 75°53'26.3"E) of Malappuram Dt., Kerala, India on 18.06.2019, Coll. Anjitha K Bhadrans.

Host range: *Coprini* sp.

Remarks: The present specimens show morphological resemblance to *U. shangaica* described by Wisniewski and Hirschmann, 1996 from China and hence fixed so. This forms the first report on the association of this species with the insect host, *X. globosa*.

Genus : *Centrouropoda* Berlese, 1917

Generic diagnosis: Dorsal setae of various nature including smooth, lanceolate or pilose. Two pairs of setae placed at the posterior part of the shield. Peritreme curved with wavy margin. A sclerotised node present on chelicerae. Two pairs of hypostomal setae long and smooth while the other two pairs pilose. All pairs of legs with pretarsus and claws.

***Centrouropoda almerodai* Hiramatsu & Hirschmann, 1992**

(Fig. 1.63)

Colour: Tan

Measurements: Length: 370–380

Width: 265–275

Description

Deutonymph:

Dorsum (Fig. 1.63 a, 1.64): Idiosoma oval and punctated, the punctation being distinctly developed along the lateral borders. Idiosomal margin undulating. Dorsal shield with 24 pairs of setae, 13 pairs on podosoma and 11 pairs on opisthosoma. Majority of dorsal setae smooth and needle like, excepting nine pairs of long and apically serrated setae.

Venter (Fig. 1.63 b): Sternal shield long, extending from the posterior level of coxa I to the posterior of coxa IV. Sternal shield with pore like ornamentation, punctations present lateral to the sternal shield. Five pairs of setae on sternal shield, all smooth and pointed. Sternal setae, *st1* originates between the level of coxa I and II, *st2* between coxae II and III, *st3* at the level of coxa III, *st4* anterior to coxa IV, and *st5* posterior to coxa IV. Ventrianal shield with four pairs of smooth and simple setae, two pairs of short and needle like anal setae. Peritreme somewhat C shaped, extending to the level of *st2*, with the stigmata placed at the posterior level of coxa II.

Gnathosoma: Movable digit of chelicerae with three teeth and fixed digit with five teeth. Palpal setae smooth and needle like.

Legs: Setae on all legs smooth and simple, leg I devoid of claws, tarsi II-IV bear thick and robust setae.

Adult: Not recovered during sampling.

Materials examined: 2 deutonymphs collected from *R. ferrugineus* at the Moolamkudam region (10°23'19.8"N 76°19'33.4"E) of Thrissur Dt., Kerala, India, on 22.10.2017; 3 deutonymphs from *R. ferrugineus* collected at Vattamkulam region (10°47'19.4"N 76°01'35.0"E), Malappuram Dt., Kerala, India on 12.11.2018, Coll. Anjitha K Bhadrán.

Host range: *R. ferrugineus*

Remarks: The present specimens resemble *C. almerodai* described by Hiramatsu and Hirschmann, 1992 from Italy in all morphological features and hence fixed so. This forms the first report of the occurrence of this species in India.

Family: Dinychidae Berlese, 1916

Genus : *Uroobovella* Berlese, 1903

Generic diagnosis: Tortoise like uropodine mites encased in armour. Pedofossae present. Peritreme sinuous with stigmata present at the level of coxae II-III. Genital shield nude. Coxa I flattened, covering most of the tritosternum. Movable digit of chelicerae with single tooth and fixed digit with a membranous process.

***Uroobovella assamomarginata* Hiramatsu & Hirschmann, 1979**

(Fig. 1.65)

Colour: Brown

Measurements: Length: 260–268

Width: 165–170

Description

Deutonymph:

Dorsum (Fig. 1.65 a, 1.64): Dorsal shield oval and punctated, bearing 35 pairs of short and spine like setae. 20 pairs of dorsal setae inserted on podosoma and 15 pairs on opisthosoma in position. Distinct circular ornamentation present between setae *j6* and *J5*.

Venter (Fig. 1.65 b): Sternal shield with eight pairs of simple and pointed sternal setae. Ventral and anal shields distinct, six pairs of setae on ventral shield and two pairs on anal shield. Sternal shield very close to the sub-rectangular ventral shield. Peritreme extends to the level of *s1*, stigmata reaching to the posterior of coxa II.

Gnathosoma: Fixed and movable digits of chelicerae well developed, cheliceral teeth not distinct.

Legs: Legs I-III with well developed ambulacra, all leg segments with short, needle like setae.

Adult: Not recovered during sampling.

Materials examined: 4 deutonymphs collected from *R. ferrugineus* at Kavanad (10°22'02.4"N 76°19'46.3"E), Thrissur Dt., Kerala, India on 16.03.2019, 2 deutonymphs collected from *R. ferrugineus* at the Calicut University Campus (11°08'01.9"N 75°53'26.3"E), Malappuram Dt., Kerala, India on 02.06.2020, Coll. Anjitha K Bhadran

Host range: *R. ferrugineus*

Remarks: The specimens greatly resemble *U. assamomarginata* described by Hiramatsu & Hirschmann, 1979 from Malaysia in all features and hence assigned to the above taxon. This forms the first report on the association of this species with *R. ferrugineus* from India.

***Uroobovella javae* Wisneiowski, 1981**

(Fig. 1.66)

Colour: Brown

Measurements: Length: 585–593

Width: 315–320

Description**Deutonymph:**

Dorsum (Fig. 1.66 a): Dorsal shield oval with 31 pairs of setae, 13 pairs inserted on the podosoma and 18 pairs on opisthosoma. Distinct circular ornamentation between setae *j4* and *JI*.

Venter (Fig. 1.66 b): Sternal shield with six pairs of simple and pointed sternal setae, three pairs of pori present on the sternal shield. Ventrianal shield with 2 pairs of setae, one pair on the ventral shield and one pair on the anal shield. Sternal shield very close to the subrectangular ventral shield. Peritremes extend to the level of *z1*, stigmata reaching the posterior of coxa II.

Gnathosoma: Fixed and movable digits of chelicera well developed, teeth not distinct.

Adult: Not recovered during sampling.

Materials examined: Three deutonymphs recovered from the legs, proboscis and body segments of *R. ferrugineus*, collected at Kavanad (10°22'02.4"N 76°19'46.3"E), Thrissur Dt., on 16.03.2019, Coll. Anjitha K Bhadrar.

Host range: *R. ferrugineus*

Remarks: The present specimens look morphologically similar to *Ujvae* Wisneiowski, 1981 reported from Indonesia and hence confirmed so. This forms the first report on the association of this species with *R. ferrugineus* from India.

***Urobovella phoenicicola* Kotschan, Tambe and Riolo, 2012**

(Fig. 1.67)

Colour: Dark brown

Measurements: Length: 375–390

Width: 255–260

Description**Deutonymph:**

Dorsum (Fig. 1.67 a): Dorsal surface smooth, with 36 pairs of setae, of which 17 pairs on podosoma and 19 pairs on opisthosoma. All dorsal setae needle like, but variable in length. Most of the dorsal setae long, but some of the central setae as shown in Fig. 1.67 a are short and pointed.

Venter (Fig. 1.67 b): Sternal shield arising posterior to coxa I and terminating with a straight posterior margin. Eight pairs of short and needle like sternal setae distributed on the long sternal shield, setae *st1* situated below the anterior border, *st2* and *st3* at the anterior and posterior to the level of coxa II, *st4* inserted slightly inwards, almost at the same level of *st3*, arising between coxae II and III, *st5* at the level of coxa III, *st6* between coxae III and IV, *st7* at the level of coxa IV and *st8* posterior to coxa IV, on the posterior border of the sternal shield. Ventrianal shield subtriangular, smooth, and with two pairs of setae. Peritreme S shaped, extending beyond *r3* and stigmata between coxae II and III.

Gnathosoma: Chelicerae developed but not extending beyond the rostrum. Teeth not distinct.

Leg: All legs with ambulacra at the tip of tarsi and have needle like setae.

Adult: Not recovered during sampling.

Materials examined: 2 deutonymphs collected from *R. ferrugineus* at Thrikkangodu (10°45'52.4"N 76°21'07.5"E), Palakkad Dt., Kerala, India on 05.11.2017; 5 deutonymphs from *R. ferrugineus* collected at Kothayur (10°47'19.4"N 76°01'35.0"E), Palakkad Dt., Kerala, India on 17.04.2019 ; 3 deutonymphs from *R. ferrugineus* collected at Vattamkulam (10°46'04.1"N 76°26'25.0"E), Palakkad Dt. Kerala, India on 12.01.2020, Coll. Anjitha K Bhadrn.

Host range: *R. phoenicis*

Remarks: The specimen examined resembles the species, *U. phoenicicola* described by Kontschan *et al.*, 2012 from Cameroon. This forms the first report of the occurrence of this species on *R. ferrugineus*.

***Uroobovella pilosetosa* Kontschan, 2012**

(Fig. 1.68)

Colour: Dark brown

Measurements: Length: 830–850

Width: 650–680

Description

Female:

Dorsum (Fig. 1.68 a): Idiosoma oval in outline, with pointed rostrum and without sculptural pattern. Dorsal shields and marginal shields fused at the anterior part of idiosoma. Dorsal surface with faint punctations medially and distinct punctations laterally. Dorsal shield with 38 pairs of setae, of which 23 pairs inserted at the anterior part of idiosoma and 15 pairs aligned posteriorly. All dorsal setae smooth and needle like, except two pairs, *J5* and *Z5* which appear pennate.

Venter (Fig. 1.68 b): Sternal shield short, extending between coxae II and IV. Sternal setae short and needle like, *st1* placed on anterior margin of genital shield, *st2* at the level of anterior margin of coxa II, *st3* at the level of posterior margin of coxa II, *st4* on level of anterior margin of coxa III, *st5* at the middle level of coxa III, *st6* near basal margin of genital shield and *st7* between coxae IV. Region surrounding coxae of legs II to IV with punctations. Ventral shield without ornamentation and with smooth and needle like setae. Adanal setae smooth and needle like, postanal setae absent.

Gnathosoma: Corniculi horn like. Fixed and movable digits of chelicerae bearing one tooth each, fixed digit with a sensory organ and appears longer than the movable digit.

Legs: Legs I-IV bear simple setae. All legs with well developed ambulacra. Leg I with prolonged ambulacrum.

Male: Not recovered during sampling.

Materials examined: 3♀♀ from *O. philemon* collected at Moolamkudam (10°23'19.8"N 76°19'33.4"E), Thrissur Dt., Kerala, India, on 19.03.2018; Coll. Anjitha K Bhadran.

Host range: Under driftwood

Remarks: The present specimen closely resembles *U. pilosetosa* Kontschan, 2012 from New Zealand in all morphological features. This forms the first report on the association of this species with the dung beetle, *O. philemon*.

Superfamily : Parasitoidea Oudemans, 1901

Family : Parasitidae Oudemans, 1901

Genus : Holoparasitus Oudemans, 1936

Generic diagnosis: Adults with well sclerotised dorsal and ventral shields. Deutonymphs with separate podonotal and opisthonotal shields, weakly sclerotised. Tritosternum of deutonymph and female normal and biramous. Genital shield of female pentagonal. Corniculi strong and notched internally. Legs of both deutonymph and female without spurs.

***Holoparasitus stramenti* Karg, 1971**

(Fig. 1.69)

Colour: Tan

Measurements: Length: 550–570

Width: 320–350

Description

Adult male:

Dorsum (Fig. 1.69 a): Dorsal shield reticulated and oval in outline. 45 pairs of simple, pointed needle like setae present on the dorsum, 20 pairs on the podonotal region and 25 pairs on the opisthonotal region. Region between *j5* and *j6* with punctations.

Venter (Fig. 1.69 b): Sterno-genital shield ornamented, and with five pairs of sternal setae. All sternal setae smooth and needle like. Seta *st1* inserted at the level of the anterior margin of coxa II, *st2* at the level of the middle of coxa II, *st3* at the level of anterior margin of coxa III, *st4* between coxae III and IV, *st5* at the level of the posterior margin of coxa IV. Peritreme extending to the level of *st1*, stigmata located between coxae III and IV. Peritrematal shield long and narrow extending down the coxa IV. The sternogenital region is strongly reticulated with five pairs of setae. Opisthogastric region with 15 pairs of setae and three anal setae.

Gnathosoma: Gnathosomal setae simple. Fixed digit of chelicerae with six teeth and movable digit with one tooth.

Legs: All legs with well developed ambulacra, rounded pulvilli and two claws. Most of the leg setae slender, except some setae on the tarsi which are pilose. Femoral apophysis of leg II strong.

Female: Not recovered during sampling.

Materials examined: 2 ♂♂, from *C. repertus*, collected at Kothayur (10°46'60.0"N 76°20'26.5"E) on 12.01.2018; 1 ♂ from *O. rhinoceros* grub collected at Kothayur (10°46'60.0"N 76°20'26.5"E), Palakkad Dt., Kerala, India on 26.07.2019, Coll. Anjitha K Bhadrar.

Host range: Found distributed in leaf litter, compost, moss etc.

Remarks: The specimens examined during the study appear morphologically similar to the species, *H. stramenti* Karg, 1971 collected from England. This forms the first report on the association of the species with dung beetle.

Genus : *Poechilochirus* G. & R. Canestrini, 1882

Generic diagnosis: Dorsal setae *z5* and *j6* of equal size in females. Genital shield fused with hologastric shield in females. Deutonymphs often with a conspicuous band on the intercoxal shield. Fixed digit of chelicerae with a membranous process. Claws of pretarsus I absent in males.

***Poechilochirus* sp.**

(Fig. 1.70)

Colour: Light brown

Measurements: Length: 980–997

Width: 683–696

Description**Deutonymph:**

Dorsum (Fig. 1.70 a): Dorsal shield reticulated and divided into podosomal and opisthosomal shields. Podosomal shield with 19 pairs of setae; eight pairs of setae pilose, nine pairs of unilaterally barbed setae and two pairs of smooth and needle like setae. Opisthosomal shield with 20 pairs of setae, one seta large and pilose and all others smooth and tapering. Lateral shield with 14 pairs of setae, of which 3 pairs unilaterally barbed and the rest needle like. Tritosternum with pilose laciniae fused at the base.

Venter (Fig. 1.70 b): Sterniti-genital shield extending between coxae I and IV, with four pairs of smooth and tapering sternal setae. Ventrianal shield triangular with pilose paranal and postanal setae. Peritreme long, extending to the level of *s*₂ and stigmata placed between coxae III and IV. Gnathotectum trifid with a triangular median prong and narrow lateral prongs. Subcapitulum with paired median prongs and four pairs of simple, tapering setae. Palp femur with five setae, one with oval head. Palp genu with six setae, two with oval head.

Gnathosoma: Movable digit of chelicerae with six teeth. Fixed digit of chelicera without well developed denticles.

Legs: Tarsi IV the longest of all other pairs. Basitarsus with four barbed setae and tarsus with 10 setae, all setae pilose.

Adult: Not recovered during sampling.

Materials examined: 2 deutonymphs, from *C. repertus*, collected at Kothayur (10°46'60.0"N 76°20'26.5"E), Palakkad Dt., Kerala, India on 12.01.2018, Coll. Anjitha K Bhadran.

Host range: Shows distribution in chicken compost and manure, and predating on houseflies.

Remarks: The deutonymphal stage of *Poecilochirus* is poorly described. The species is similar to the deutonymph of *Poecilochirus monospinosus* described by Wise, Hennessey and Axtell (1988) in the characters of dorsal setae, tectum and palpal femur and genu. However, the present species differs from the above species in the following characters: (1) Podosomal shield with 19 pairs of setae and opisthosomal shield with 20 pairs of setae (podosomal shield with 21 pairs of setae and opisthosomal shield with 13 pairs of setae in *P. monospinosus*); (2) median prong of the same length as lateral prongs (median prong longer than lateral prongs in *P. monospinosus*); (3) tarsus IV with 10 setae (tarsus IV with 12 setae in *P. monospinosus*) and (4) infracapitulum with one pair of serrated setae and three pairs of smooth setae (infracapitulum with four pairs of serrated setae in *P. monospinosus*). The genus is reported for the first time from dung beetle.

Superfamily : Rhodacaroidea Oudemans, 1902

Family : Digamasellidae Evans, 1957

Genus : Digamasellus Berlese, 1905

Generic diagnosis: Seta *z*3 absent in *Digamasellus* spp., seta *s*2 inserted more laterally compared to *z*3. Triangular plates bearing genital setae present between coxa IV. Femur, genu, tibia and tarsus II of males bear apophyses or spurs. Six transverse lines present on hypostome in both sexes. The fourth pair of sternal setae of females present on the sternum. Protonymphs with spines and very long setae on pygidial shield. Leg setation variable.

***Digamasellus neodisetus* Hurlbutt, 1967**

(Fig. 1.71)

Colour: Transparent- white

Measurements: Length: 210–225

Width: 135–155

Description

Protonymph:

Dorsum (Fig. 1.71 a): Two distinct lateral shields on podosoma. Dorsal shield with 30 pairs of filiform setae. Opisthosoma with ornamentations, setae on opisthosoma longer than podosomal setae.

Venter (Fig. 1.71 b): Sternal shield with four sternal setae, *st5* placed far posteriorly on the integument. Anal shield vase shaped, with anal setae. Seta *Jv5* longer among all the ventral setae.

Gnathosoma: Fixed digit of chelicerae with four teeth and movable digit with eight teeth.

Legs: Leg IV with macrosetae on genu and tibia. Chaetotaxy of leg IV: Co 1- Tr 2- Fe 3- Ge 5- Ti 6- Ta 10.

Adult: Not recovered during sampling.

Materials examined: 3 protonymphs, from *O. rhinoceros* grub collected at Kothayur (10°46'60.0"N 76°20'26.5"E), Palakkad Dt., Kerala, India on 26.07.2019, Coll. Anjitha K Bhadrán.

Host range: Shows distribution in galleries of elm bark beetle.

Remarks: The specimen examined is similar to *D. neodisetus* described by Hurlbutt, 1967 from Ohio in all respects except in the length of some dorsal setae. This forms the first report on the occurrence of this species on *O. rhinoceros* grub.

Digamasellus quadrisetus (Berlese, 1921)

(Fig. 1.72)

Colour: Transparent- white

Measurements: Length: 420–435

Width: 175–180

Description**Deutonymph:**

Dorsum (Fig. 1.72 a): Anterior dorsal shield with 20 pairs simple and pointed setae. A 'Y' shaped notch at the posteromedian part of the anterior dorsal shield. Posterior dorsal shield with 14 pairs of setae.

Venter (Fig. 1.72 b): Sternal shield smooth with five pairs of sternal setae. Setae on sternal shield smooth and swollen at the base. Ventrianal shield large, very close to the sternal shield and bears six pairs of preanal setae, *Jv1*, *Jv2*, *Zv1*, *Zv2*, *Zv3* and three anal setae, *pa* and *po*.

Gnathosoma: Chelicera with three teeth on the fixed digit and seven teeth on the movable digit. All legs ending with well developed ambulacrum.

Legs: Leg IV with needle like setae. Genu IV with six setae.

Adult: Not recovered during sampling.

Materials examined: 4 deutonymphs, from *R. ferrugineus* collected at Poovattuparambu (11°16'11.4"N 75°53'05.3"E), Kozhikode Dt., Kerala, India on 29.05.2018; 5 deutonymphs from *R. ferrugineus* collected at Muthoor (10°48'11.2"N 76°00'55.7"E), Malappuram Dt., Kerala, India on 16.08.2018, Coll. Anjitha K Bhadran.

Host range: Distributed in the galleries of *Ips tyrophagus*.

Remarks: The specimen examined during the study greatly resembles the species, *D. quadrisetus* described by Berlese (1921) from California in all morphological details and hence fixed so. This forms the first report on the occurrence of this species on *R. ferrugineus*.

Superfamily : Eviphidoidea Berlese, 1913

Family : Eviphididae Berlese, 1913

Genus : Alliphis Halbert, 1923

Generic diagnosis: Dorsal shield with seta *j1* lanceolate. All dorsal setae subequal, short and uniform in length. Peritrematal shields not connected with each other and

fused to anterolateral parts of the dorsal shield. Presternal and metasternal plates present. Movable cheliceral digit unidentate and fixed digit without hyaline appendage.

***Alliphis halleri* (G. R. Canestrini, 1881)**

(Fig. 1.73)

Colour: Creamy white

Measurements: Length: 445–502

Width: 225–310

Description

Adult female:

Dorsum (Fig. 1.73 a): Dorsal shield with 30 pairs of setae and polygonal ornamentations, widest at the setal position, *r*8. All the 30 pairs of dorsal setae smooth and tapered except *j*1 which is blunt ended. Seta *z*1 shortest of all dorsal setae. Setal pattern 20A:10B. Tritosternum with pilose laciniae.

Venter (Fig. 1.73 b): Sternal shield with a straight anterior border and a slightly concave posterior border, bearing three pairs of needle like pointed sternal setae. Seta *st*4 located on the oval metasternal plate. Genital shield tongue shaped with a pair of setae, *st*5. Anal shield subtriangular with rounded anterior region and concave posterior region with subequal para-anal and post-anal setae. Peritreme long and extends to the level of *z*1 and stigmata placed at the level of coxae IV. Deutosternum with six rows of denticles, corniculi large and curved inwards.

Gnathosoma: Fixed digit of chelicerae with four teeth, median tooth being large and triangular, pilus dentilis very fine. Movable digit with a single robust tooth.

Legs: All tarsi ending with a pair of claws. Leg chaetotaxy: Co 2-2-2-1, Tr 6-5-5-5, Fe 13-11-6-6, Ge 11-11-8-7, Ti 11-10-7-7, Ta 16-18-18-18. All setae smooth and pointed. Most of the dorsal setae thicker than the ventral and lateral setae.

Male: Not recovered during sampling.

Materials examined: 4 ♀♀, from *M. leda ismene*, collected at Kadakkattupara (11°07'48.8"N 75°52'49.7"E), Malappuram Dt., Kerala, India on 15.06.2018, Coll. Anjitha K Bhadran.

Host range: *Bubas bubalus*, *Geotrupes spiniger*, *Onthophagus vacca*, *Gymnopleurus mopsus* and *Copris hispanus*. Also distributed in leaf compost and grass compost.

Remarks: The present specimen is very similar to *A. halleri* described by G. & R. Canestrini, 1881. This forms the first report of the species from *M. leda ismene*.

***Alliphis* sp.**

(Fig. 1.74)

Colour: Light brown

Measurements: Length: 515

Width: 286

Description

Deutonymph:

Dorsum (Fig. 1.74 a): Dorsal shield ornamented with spherical foveoles, the latter very distinct at the middle giving the appearance of a distinct central shield. The shield bears 36 pairs of dorsal setae, all smooth, stout and needle like.

Venter (Fig. 1.74 b): Sterniti-genital shield with four pairs of small needle like setae. Ventrianal shield not distinct. Peritreme long and extending to the level of coxa I and stigmata placed at the level of coxa III. Deutosternum with five rows of denticles.

Gnathosoma: Gnathotectum mucronate, with small denticulations. Fixed digit of chelicerae with three teeth, median tooth being large and triangular. Movable digit with a single tooth.

Legs: All tarsi ending with a pair of claws. Leg chaetotaxy: Co 2-2-2-1, Tr 6-5-5-5, Fe 13-11-6-6, Ge 11-11-8-7, Ti 11-10-7-7, Ta 16-18-18-18. All setae smooth and pointed. Most of the dorsal setae thicker than the ventral and lateral setae.

Adult: Not recovered during sampling.

Materials examined: One deutonymph, from *C. molossus* collected at Kothayur (10°46'60.0"N 76°20'26.5"E), Palakkad Dt., Kerala, India on 12.01.2018, Coll. Anjitha K Bhadran.

Host range: *Bubas bubalus*, *Geotrupes spiniger*, *Onthophagus vacca*, *Gymnopleurus mopsus*, *Copris hispanus*.

Remarks: The members of the genus is found in association with dung beetles like *B. bubalus*, *G. spiniger*, *O. vacca*, *G. mopsus*, *C. hispanus* and some species of Lepidoptera. This is the first record on the association of a member of the genus *Alliphis* with dung beetle in India.

Family: Macrochelidae Vitzthum, 1930

Genus : *Macrocheles* Latreille, 1829

Generic diagnosis: Dorsal shield variable nature such as smooth, reticulate or punctate with pore like structures. Wide range of setal forms occurs, commonly with simple or finely pilose setae and rarely with coarsely serrated setae. Podonotal and opisthonotal shields completely fused in adults. Corniculi horn like with 5-7 transverse rows of denticles. Digits of chelicerae short and stout, pilus dentilis present, arthroal membrane brush like.

Macrocheles glaber (Muller, 1860)

(Fig. 1.75)

Colour: Light brown

Measurements: Length: Length: 815–850

Width: 500–515

Description

Adult female:

Dorsum (Fig. 1.75 a): Dorsum oval, widest at the level of seta *SI*, ornamented with punctations arranged as polygonal reticulations and pore like structures. Dorsal shield

partitioned in to two parts by a concave band like structure lying underneath the seta *z6*. Dorsum with 28 pairs of setae, mostly with pointed tips and four pairs like *j1*, *j4*, *z4* and *J5* pilose.

Venter (Fig. 1.75 b): Sternal shield longer than wide, heavily ornamented with one linearcuata. Three pairs of sternal setae, *st1*, *st2* and *st3* on sternal shield, one pair of setae, *st4* on metasternal shield. Genital shield ornamented with one pair of sternal setae, *st5*. Ventrianal shield heavily ornamented, wide at *Jv2*, with three pairs of preanal setae (*Jv1*, *Jv2* and *Jv3*) and anal setae (*pa* and *po*).

Gnathosoma: Chelicera with four teeth on the fixed digit and the movable digit appears monodentate.

Legs: Leg spurs and tubercles well developed. Leg II stouter than others. Leg II-IV have well developed ambulatory structures. Genu IV with six simple setae.

Male: Not recovered during sampling.

Materials examined: 3 ♀♀, from the body of *O. philemon*, collected at Kuttikadu (10°33'15.5"N 76°16'41.1"E), Thrissur Dt., Kerala, India on 16.10.2017, Coll. Anjitha K Bhadran

Host range: Distributed in moss, lichen, bark, soil, straw, dung, litter under *Pinus* sp., *Pyrus* sp., *Salix* sp.

Remarks: The specimen examined confirms with the species, *M. glaber* described by (Muller, 1860) in all characters and hence assigned to the same taxon. This forms the first report of the occurrence of the species on dung beetle.

***Macrocheles krantzi* Evans & Hyatt, 1963**

(Fig. 1.76)

Colour: Brown

Measurements: Length: 530–550

Width: 290–310

Description

Adult female:

Dorsum (Fig. 1.76 a): Dorsal shield with reticulated ornamentations and pore like structures present on dorsal shield. 28 pairs of short, slender and simple setae present on the dorsum. A distinct line passing below seta *jl*.

Venter (Fig. 1.76 b): Sternal shield short and ornamented with punctations, truncated posteriorly. Sternal shield with lateral ornamentations and two sternal pores. Linea arcuata short and punctate. Three pairs of sternal setae on sternal shield (*st1*, *st2* and *st3*), one on metasternal shield (*st4*) and one on genital shield (*st5*). Ventrianal shield truncated posteriorly, ovoid and with transverse reticulation. Three pairs of preanal setae (*Jv1*, *Jv2* and *Jv3*) and anal setae (*pa* and *po*) present on ventrianal shield.

Gnathosoma: Chelicera with three teeth on movable digit and two teeth on fixed digit, pilus dentilis present.

Leg: Legs II-IV with well developed ambulacrum. Tarsus I without ambulacrum. Genu IV with six simple setae.

Male: Not recovered during sampling.

Materials examined: 4 ♀♀ from *R. ferrugineus*, collected at Moolamkudam region (10°23'19.8"N 76°19'33.4"E), Thrissur Dt., Kerala, India on 14.09.2018; 2 ♀♀ from *C. repertus* collected at Vattamkulam (10°47'19.4"N 76°01'35.0"E), Malappuram Dt., Kerala, India on 13.08.2019, Coll. Anjitha K Bhadrar.

Host range: *Scarabaeus brahminus*, *Scarabaeus erichsoni*, distributed in soil also.

Remarks: The specimen examined resembles the species *M. krantzi* described by Evans and Hyatt (1963) in all characters and hence confirmed so. This forms the first report of the occurrence of this species from *R. ferrugineus*.

***Macrocheles muscaedomesticae* (Scopoli, 1772)**

(Fig. 1.77)

Colour: Brown

Measurements: Length: 980–1005

Width: 655–670

Description

Adult Female:

Dorsum (Fig. 1.77 a): Dorsal plate oval with punctations arranged in a reticulated pattern. 28 pairs of dorsal setae present on the dorsum, of which *j1* distally pilose, *J5* slightly pilose. Seven pairs of setae, *j2*, *j5*, *j6*, *z1*, *z5*, *z6*, and *J2* smooth and needle like, other setae pilose.

Venter (Fig. 1.77 b): Sternal shield heavily ornamented with punctate ornamentations. Three pairs of sternal setae, *st1*, *st2* and *st3* on sternum, one pair, *st4* of metasternal shield. Genital shield truncated posteriorly with lateral ornamentations, *st5* inserted postero-laterally. Ventrianal shield longer than wide, widest at the seta, *Jv2*. Three pairs of preanal setae (*Jv1*, *Jv2* and *Jv3*) and anal setae (*pa* and *po*) on heavily ornamented ventrianal shield.

Gnathosoma: Chelicerae with four teeth on movable digit and one tooth on fixed digit.

Leg: Legs II-IV with well developed ambulacra. All leg segments with simple setae. Genu IV with five simple setae.

Male: Not recovered during sampling.

Materials examined: 1♀ from *C. sordidus* collected at Panamanna (10°48'34.9"N 76°21'00.2"E), Palakad Dt. Kerala, India on 27.05.2017; 2♀♀ from *O. longicollis*, collected at Muthoor (10°48'11.2"N 76°00'55.7"E), Malappuram Dt., Kerala, India on 11.01.2018; 2 ♀♀ from *C. sordidus* collected at Kavanad (10°22'02.4"N 76°19'46.3"E), Thrissur Dt., Kerala, India on 10.04.2019, Coll. Anjitha K Bhadrans.

Host range: *Musca domestica*, *Stomoxys calcitrans*, bumblebees, honeybees, and soil.

Remarks: The specimen examined is very similar to *M. muscaedomesticae* described by Scopoli, 1772 in all features. This forms the first report of the occurrence of this species from *O. longicollis*.

Macrocheles perglaber Filipponi & Pegazzano, 1962

(Fig. 1.78)

Colour: Brown

Measurements: Length: 850–980

Width: 500–530

Description

Female:

Dorsum (Fig. 1.78 a): Dorsal shield oval, widest at the level of seta *r4* and with 28 pairs of setae. Most of the setae needle like, but 10 pairs of setae such as *j1*, *j4*, *z4*, *S5*, *r2*, *r3*, *J4*, *J5*, *S4* and *S5* pilose. Dorsal shield ornamented with sculptures arranged in reticulated pattern. A distinct suture passes through the middle of the dorsal shield, between *z6* and *J2*.

Venter (Fig. 1.78 b): Sternal shield heavily ornamented with two lineae arcuatae and three pairs of setae, *st1*, *st2* and *st3*. Sternal setae *st4* placed on the metasternal shield and *st5* on the genital shield. Ventrianal shield longer than wide, heavily ornamented with three pairs of preanal setae, *Jv1*, *Jv2*, *Jv3* and anal setae (*pa* and *po*). Peritreme extending to seta *z1* with stigmata in between coxae III and IV.

Gnathosoma: Chelicera with three teeth on fixed digit and two teeth on movable digit.

Leg: Genu IV with five setae, three serrated and two simple. Most of the leg segments with simple, needle like setae

Male: Not recovered during sampling.

Materials examined: 2♀♀, from *O. rhinoceros* grub collected at V. R. Puram (10°18'44.4"N 76°19'19.4"E), Thrissur Dt. on 13.06.2019; 2♀♀ from *R. ferrugineus* grub, collected at Moolamkudam region (10°23'19.8"N 76°19'33.4"E), Thrissur Dt., Kerala, India on 14.09.2018, Coll. Anjitha K Bhadrán

Habitatrange: shows distribution in dung, straw, weeds.

Remarks: The specimen examined is very similar to *M. perglaber* described by Filipponi & Pegazzano, 1962 in all characters. This forms the first report of the occurrence of *M. perglaber* on the grub of *O. rhinoceros*.

Superfamily : Phytoseioidea Berlese, 1916

Family : Phytoseiidae Berlese, 1916

Subfamily : Amblyseiinae Muma, 1961

Tribe : Amblyseiini Muma, 1961

Subtribe : Amblyseiina Chant & Mc Murtry, 2004

Genus : *Amblyseius* Berlese, 1914

Generic diagnosis: Dorsal shield with 17 pairs of setae. Dorsal setae *Z5*, *s4* and *Z4* whip like. Peritreme extending upto *j1*. Sternal shield with three pairs of setae. Macrosetae present on genu, tibia and tarsus of leg IV.

Amblyseius channabasavannai Gupta & Daniel, 1978

(Fig. 1.79)

Colour: Transparent white

Measurement: Length: 325–335

Width: 210–215

Description

Adult Female:

Dorsum (Fig. 1.79 a): Dorsal shield smooth with 18 pairs of setae. Dorsal setae smooth and pointed; *j1*, *j3*, *s4*, *Z4* and *Z5* longer than all other equal sized setae, *Z5* the longest and whip like. Setae *r3* and *R1* placed on the lateral integument.

Venter (Fig. 1.79 b): Sternal shield with three pairs of sternal setae, *st1*, *st2* & *st3*. Genital shield with one pair of seta, *st5*. Ventrianal shield longer than wide, widest at the level of seta, *Zv2*. Ventrianal shield with three pairs of preanal setae, *Jv1*, *Zv2* and *Jv2*. Peritreme extending to *j1* anteriorly, stigmata placed at the level of coxa IV. Spermatheca with tubular cervix and parallel walls as shown in the figure. 1.79 b.

Gnathosoma: Fixed digit of chelicerae multidentate and movable digit with four teeth.

Leg: Macrosetae on leg IV placed on genu, tibia and basitarsus. Leg chaetotaxy: genu II 2, 2/0, 2/0, 1; tibia II 1, 1/1, 2/1, 1; genu III 1, 2/1, 2/0, 1; tibia III 1, 1/1, 2/1, 1.

Male: Not recovered during sampling.

Materials examined: 3♀♀, from *B. tabaci* infested chilli plants collected at Manissery (10°46'43.1"N 76°20'26.2"E), Palakkad Dt., Kerala, India on 16.11.2021, Coll. Anjitha K Bhadran.

Habitat range: Mango, jute, citrus, neem, champa, *Shorea robusta*, *Lantana*, chrysanthemum, Dahlia.

Remarks: The specimen examined is similar to *A. channabasavannai* described by Gupta & Daniel, 1978 from Trivandrum in all characters. This forms the first report of the species associated with whiteflies on chilli.

***Amblyseius largoensis* (Muma, 1955)**

(Fig. 1.80)

Colour: Transparent -white.

Measurements: Length: 370–375

Width: 275–280

Description

Adult Female:

Dorsum (Fig. 1.80 a): Dorsal shield with 18 pairs of setae, of which *j1*, *j3*, *s4*, *Z4*, *Z5* longer than the other dorsal setae, *j4*, *j5*, *j6*, *z2*, *z4*, *z5*, *r3*, *J2*, *Z1*, *R1*, *S4*, *S5*, *J5* short and of same length. *Z5* long and whip like. The sublateral setae *r3* and *R1* present on lateral integument. Setal pattern 10A: 8B.

Venter (Fig. 1.80 b): Sternal shield longer than wide and with three pairs of setae, *st1*, *st2* & *st3*. Sternal seta *st4* located on the integument. Genital shield with one pair of seta, *st5*. Ventrianal shield with three pairs of preanal setae, *Jv1*, *Jv2* and *Zv2* and a pair of semilunar pores. Peritreme extending to the level of *j1*. Two pairs of metapodal plates present. The cervix of spermatheca tubular with parallel walls.

Gnathosoma: Fixed digit of chelicerae with seven teeth, three posterior and four anterior to pilus dentilis. Movable digit of chelicera with two teeth.

Leg: Macrosetae on genu, tibia and basitarsus of leg IV. Chaetotaxy of genu II: 2, 2/0, 2/0, 1, tibia II: 1, 1/1, 2/1, 1, genu III: 1, 2/1, 2/0, 1 and tibia III: 1, 1/1, 2/1, 1.

Male: The arrangement of setae on dorsum very similar to that of the female. Ventrum with 5 pairs of sternal setae on sternogenital shield.

Materials examined: 3 ♀♀ and 1 ♂ from *B. tabaci* infested chilli leaves collected at Kuttikadu region (latitude 10.5484° and longitude 76.2857°), Thrissur Dt., Kerala, India on 12.03.2020; 2 ♀♀ from *A. floccosus* infested guava leaves collected at Kuttikadu region (latitude 10.5484° and longitude 76.2857°), Thrissur Dt., Kerala, India on 12.03.2020, Coll. Anjitha K Bhadran.

Habitat range: *Mangifera indica*, *Calophyllum inophyllum*, *Musandra corymbosa*, *Tabernaemontana coronaria*, *Tectona grandis*, *Dalbergia*, beans, citrus, pomegranate, black berry, sugarcane, *Cassia*, cashew nut, bamboo, arecanut, fig, guava, chilli, *Shorea* sp., papaya, pepper, dahlia, china rose, poppy, pine cone, grass, dahlia, *Citrus medica*, *Mallotus* sp, *Alstonia scholaris*, *Anona squamosa*, *Calotropis*, *Suaedanufi flora*, *Jasminum sambac*, *Basicophia javanica*, *Phoenix paludosa*, *Shorea robusta*, banyan, peach, sapota, jackfruit, cotton, tea, arum.

Remarks: The specimen examined resembles *A. largoensis* (Muma, 1955) reported from Florida in all features. This forms the first report of this species associated with *B. tabaci* from India.

Amblyseius vasiformis Moraes & Mesa, 1991

(Fig. 1.81)

Colour: Transparent white

Measurements: Length: 410–420

Width: 270–275

Description

Adult Female:

Dorsum(Fig. 1.81 a): Dorsal shield smooth with 17 pairs of setae; *j1, j3, j4, j5, j6, z2, z4, z5, s4, J2, J5, Z1, Z4, Z5, S2, S4, S5* and lateral integument with two pairs of setae, *r3* and *R1*. Setal pattern 10A:9B. All dorsal setae smooth and simple except *Z4* and *Z5* which appear slightly light serrated. All setae short except *j1, j3, s4, Z4* and *Z5*, which look longer and of variable length, *Z5* being the longest. Two pairs of setae, *r3* and *R1* sublateral.

Venter (Fig. 1.81 b): Sternal shield as long as wide, with three pairs of setae. One pair of sternal setae, *st4* on the integument and *st5* situated on the genital shield. Peritreme extends to the level of *j1*. Ventrianal shield vase shaped, wider towards the anus. Ventrianal shield with three pairs of preanal setae, *Jv1, Jv2, Zv2*, anal setae and one pair of pore.

Gnathosoma: Chelicera with 14-15 teeth on fixed digit and 4-5 teeth on movable digit. Cervix of spermatheca funnel shaped.

Legs: Macrosetae setaceous and seen on all the segments; *SgeI, SgeII, SgeIII, SgeIV* on the genu of legs I-IV; *Sti III* and *Sti IV* on tibia I & IV and *StIV* on tarsus IV. Chaetotaxy of genu II: 2, 2/0, 2/0, 1 and genu III: 1, 2/1, 2/1, 1.

Male: Not recovered during sampling.

Specimens examined: 8♀♀ from *B. tabaci* infested chilli collected at Moolamkudam region (latitude 10.3838° and longitude 76.3256°), Thrissur Dt., Kerala, India on 05.03.2020, Coll. Anjitha K Bhadrán.

Habitat range: *Bixa orellana, Carica papaya, Citrus* sp., *Coffea* sp., *Cocos nucifera, C. aurantifolia, C. reticulata, Jatrophiagossypiense, Matisia cordata, Pisidium guajava, Mangifera indica, Manihot esculenta, Morchella esculenta, Malva viscuspenduliflorus, Threobroma cacao, Solanum caricaefolium*.

Remarks: The specimen examined resembles *A. vasiformis* Moraes & Mesa, 1991 reported from Latin America in all features. This forms the first report of the species from chilli.

Tribe : Neoseiulini Chant & Mc Murtry, 2007

Genus: *Neoseiulus*

Generic diagnosis: Dorsal shield with 19 pairs of setae. Sternal shield with three pairs of setae. Ventrianal shield pentagonal and elongate with three pairs of preanal setae. Fixed digit of chelicerae with 4-8 teeth. Macrosetae present on leg IV.

***Neoseiulus mapuche* Ferragut & Navia, 2015**

(Fig. 1.82)

Colour: Transparent white

Measurements: Length: 335–350

Width: 205–215

Description

Adult Male:

Dorsum (Fig. 1.82 a): Dorsal shield oval, distinctly reticulated and bears 19 pairs of setae, *Z4* and *Z5* serrated and longer than all the other short and smooth setae; *J5* smallest among all the setae and *Z5* the longest. Dorsum with seven pairs of solenostomes, *gd1*, *gd2*, *gd4*, *gd5*, *gd6*, *gd8* and *gd9*.

Venter (Fig. 1.82 b): Sternal shield smooth, bearing five pairs of smooth and pointed sternal setae. Ventrianal shield reticulated with four pairs of preanal setae, *Jv1*, *Jv2*, *Zv1*, *Zv2* and anal setae. Peritreme extending to the base of *j1*, stigmata between coxa III and IV.

Gnathosoma: Fixed digit with two strong teeth and three to five small denticles. Movable digit with one tooth.

Leg: with curved macrosetae on tibia IV.

Female: not recovered during sampling.

Materials examined: 2 ♂♂ from *O. hyla* collected at Thalappara (11°04'42.9"N 75°54'12.6"E), Malappuram Dt., Kerala, India. on 10.12.2018, Coll. Anjitha K Bhadran.

Habitat range: *Saxegothaea conspicua*

Remarks: The specimen examined is similar to *N.mapuche* Ferragut & Navia, 2015 described from Argentina in all features. This forms the first report of occurrence of the species with *O. hyla*.

Genus : *Euseius* De Leon, 1967

Generic diagnosis: Dorsal shield with six pairs of dorsocentral setae. Chelicera small and fixed digit with 0-2 teeth. Sternal shield wider than long, indistinctly lobate on posterior side. Peritreme extends upto *j1*. Ventrianal shield elongate and often vase shaped. Genu, tibia and basitarsus of leg IV with macrosetae.

***Euseius finlandicus* (Oudemans, 1915)**

(Fig. 1.83)

Colour: Transparent white

Measurements: Length: 315–325

Width: 225–232

Description

Adult Female:

Dorsum (Fig. 1.83 a): Dorsal shield smooth with 17 pairs of setae, seta *Z5* longer than the remaining dorsal setae. Setal pattern 9A: 8B. All dorsal setae simple and smooth. Sublateral setae absent.

Venter (Fig. 1.83 b): Sternal shield longer than wide, with three pairs of sternal setae. *st5* present on the genital shield and *st4* present on the integument. Ventri anal shield longer than wide, with three pairs of preanal setae, *Jv1*, *Jv2* and *Zv2*. *Zv2* placed above *Jv2*, the latter inserted at the same level of *Jv1*. Peritreme extending to the level of *j3* anteriorly. Spermatheca with a tubular cervix.

Gnathosoma: The fixed digit of chelicera with two teeth and the movable digit with one tooth.

Legs: Macrosetae present on the genu, tibia and basitarsus of leg IV. Leg chaetotaxy: genu II: 2, 2/0, 2/0, 1; tibia II: 1, 1/1, 2/1, 1; genu III: 1, 1/1, 2/1, 1; tibia III: 1, 2/1, 1/1, 1.

Male: Not recovered during sampling.

Materials examined: 4♀ from *B. tabaci* infested leaves of brinjal collected at Kuttikadu region (10°33'15.5"N 76°16'41.1"E), Thrissur Dt; KAU on 23.02.2020; 3♀ from *B. tabaci* infested leaves of brinjal collected at Vellanikkara (10°32'52.1"N 76°16'59.8"E), Thrissur Dt., Kerala, India on 20.02.2020, Coll. Anjitha K Bhadran.

Habitat range: Maize, chinar, grape, tea, peach, pine, citrus, apple, castor, bamboo, cotton, arum, cashewnut, palm, coconut, datepalm, fig, banana, orchid, cardamom, lemon, mango, mulberry, chrysanthemum, *Shorea robusta*, *Amaranthus*, *Ipomoea*, *Ficus racemosa*, *Pyrus communis*.

Remarks: The specimen examined during the study resembles *E. finlandicus* (Oudemans, 1915) from Netherlands in all respects. This forms the first report of the species associated with *B. tabaci*.

***Euseius ovalis* (Evans, 1953)**

(Fig. 1.84)

Colour: Transparent -white

Measurements: Length: 360–365

Width: 235–240

Description

Adult Female:

Dorsum (Fig. 1.84 a): Dorsal shield smooth with 17 pairs of setae, setal pattern 10A: 9B. All dorsal setae simple and smooth except *j1* and *Z5*, the latter two setal pairs longer than the remaining dorsal setae. Setae *r3* and *R1* present on the lateral integument.

Venter (Fig. 1.84 b): Sternal shield with three pairs of setae, the length and width of of the sternal shield more or less equal. Genital shield bears the seta *st5*. Ventrianal shield longer than wide, with three pairs of preanal setae, *Jv1* and *Jv2* placed at the same level and *Zv2* placed anterior to the latter. Peritreme extending to the level of *j1*. Spermatheca with tubular funnel shaped cervix.

Gnathosoma: Two teeth present on the fixed digit of the chelicera and the movable digit with one tooth.

Legs: Macrosetae present on the genu, tibia and basitarsus of leg IV. Leg chaetotaxy: genu II: 2, 2/0, 2/0, 1; tibia II: 1, 1/1, 2/1, 1; genu III: 1, 2/0, 2/1, 1; tibia III: 1, 1/1, 2/1, 1.

Male: Not recovered during sampling.

Materials examined: 5♀♀ from *B. tabaci* infested chilli leaves collected at Kuttikadu region (10°33'15.5"N 76°16'41.1"E), Thrissur Dt. on 12.03.2020; 3♀♀ from *B. tabaci* infested spinach (Chekkurmanis) collected at Vellanikkara (10°32'52.1"N 76°16'59.8"E), Thrissur Dt., Kerala, India on 16.03.2020, Coll. Anjitha K Bhadran.

Habitat range: *Ficus*, *Terminalia arjuna*, banana, *Vitex pubescens*, napier grass, castor, mango, coconut, paddy, sugarcane, cashewnut, oilseed plant, *Bauhinia purpuria*, chilli, arum, cotton, brinjal, date palm, guava, *Macrocosma niculatus*, *Holorrhenaanti dysenterica*, *Tabernaemontana*, *Cassia fistula*, *Dolichos lablab*, *Glycosmis pentaphylla*, *Bougainvillea spectabilis*, *Luffa acutangula*.

Remarks: The specimen examined resembles *E. ovalis* described by Evans (1953) from S E Asia. This forms the first report of the species associated with white flies from Kerala and the second report from India associated with *B. tabaci*.

Genus: *Transeius* Chant & McMurtry, 2004

Generic diagnosis: Dorsal shield smooth or reticulated with lyrifissures or pores. Most of the dorsal setae smooth except for some serrated idiosomal ones. Sternal shield with three pairs of setae, seta *st4* placed on a separate metasternal shield. Ventrianal shield mostly pentagonal. Peritreme reaching the level of *j1*. Leg IV with macrosetae.

Transeius kroeffi Goncalves & Ferla, 2017

(Fig. 1.85)

Colour: Transparent white

Measurements: Length: 345–355

Width: 248–256

Description

Adult Female:

Dorsum (Fig. 1.85 a): Dorsal shield reticulated with 19 pairs of setae, idiosomalsetal pattern 10A: 9B. Setae *s4*, *Z4* and *Z5* longer than the remaining dorsal setae and serrated at their distal halves. All the other dorsal setae smooth. Sublateral setae, *r3* and *R1* present on the lateral integument. Seven pairs of pores and six pairs of lyrifissures present on the dorsal shield.

Venter (Fig. 1.85 b): Sternal shield with three pairs of setae and two pairs of lyrifissures. Genital shield longer than wide, with a single pair of seta *st5*. Ventrianal shield with three pairs of preanal setae and a pair of lyrifissures, wider at the level of anus and *Zv2*. Peritreme extending to the level of *j1*. Two pairs of metapodal plates present. Spermatheca with elongate tubular calyx and round vesicle.

Gnathosoma: Chelicera with three teeth on movable digit and 12 teeth on fixed digit, pilus dentilis present.

Legs: Smooth and pointed macrosetae present on all legs. Chaetotaxy: genu II 2,2/0,2/0,1; genu III 1,2/1,2/0,1

Male: Dorsal shield (length: 403, width: 190) chaetotaxy similar to that of female, but shield length and width smaller than that of the female. Sternogenital shield with five pairs of setae. Ventrianal shield wider at the level of *Zv2* and narrowing towards the anus. Chelicerae with three teeth on movable digit and seven teeth on fixed digit. Chaetotaxy of genu II and III similar to that of females.

Specimens examined: 3♀♀ and 2♂♂, from *B. tabaci* infested chilli collected at V. R. puram region (10°18'44.4"N 76°19'19.4"E), Thrissur Dt. on 18.02.2020; 2♀♀ from *B. tabaci* infested chilli collected at Manissery (10°46'43.1"N 76°20'26.2"E), Palakkad Dt., Kerala, India on 11.01.2020, Coll. Anjitha K Bhadran.

Habitat range: *Dicksonia sellowiana*, *Myrcia retorta*, *Solanum sanctaecatharinae*.

Remarks: The specimen examined resembles the species, *T. kroeffis* Goncalves and Ferla, 2017 reported from Brazil. This forms the first report of its association with whitefly.

Family: *Blattisociidae* Garman, 1948

Genus: *Lasioseius* Berlese, 1916

Lasioseius confusus Evans, 1958

(Fig. 1.86)

Colour: Tan

Measurements: Length: 450–480

Width: 270–280

Description

Adult Female:

Dorsum (Fig. 1.86 a): Dorsal shield oval and reticulated, with 33 pairs of simple and pointed setae, 8 pairs of setae on lateral shield. 15 pairs of setae on the posterior region, median setae longer than the anterior setae. Lateral shield with eight pairs of strong and spinelike setae.

Venter (Fig. 1.86 b): Sternal shield ornamented and bears with three pairs of setae and two pairs of lyrifissures. Fourth pair of setae inserted on metasternal plates. Genital shield sclerotised and with one pair of setae. Two pairs of metapodal plates located between genital and anal shields. Ventrianal shield large, with strong ornamentations and reticulations. Six pairs of simple and pointed preanal setae on ventrianal shield, anal setae of the same size as the preanal setae.

Gnathosoma: Fixed digit of chelicera multidentate; movable digit with three teeth.

Legs: Legs without macrosetae.

Materials examined: 5 ♀♀, from *O. rhinoceros*, collected at Kuttikad (10°33'15.5"N 76°16'41.1"E), Thrissur Dt. on 06.09.2018; 2 ♀♀ from *O. rhinoceros* collected at

Moolamkudam (10°23'19.8"N 76°19'33.4"E), Thrissur Dt., Kerala, India on 23.01.2019, Coll. Anjitha K Bhadran.

Habitat range: soil, maple swamp.

Remarks: The specimen examined is similar to *L. confusus* described by Evans, 1958 from British Isle. This forms the first report of the species from *O. rhinoceros*.

Subgenus : *Lasioseius* (*Lasioseius*)

Species group: *porulosus*

Lasioseius (*Lasioseius*) *moolamkudensis* sp. nov.

(Fig. 1.92)

Colour: Tan

Measurements: Length: 680 (678–682)

Width: 283 (280–285)

Generic diagnosis: Anterior margin of epistome convex and smooth. Movable digit of chelicerae with four teeth; fixed digit with 11 teeth. Dorsal shield reticulate with 31 pairs of lanceolate setae. Some of the posterior shield setae barbed. Lacinia of tritosternum fused for more than half of its total length. Sternal shield smooth, with three pairs of setae. Ventrianal shield about as long as wide with four pairs of ventral setae, paranal setae and post anal setae. Sperm access system of female with well developed major and minor duct, latter being sac like with a horned appendage.

Adult Female:

Dorsum (Fig. 1.87 a, 1.91, 1.92): Dorsal shield lightly reticulated with 31 pairs of setae, three pairs of setae; *r5*, *R1* and *R5* placed off shield on the cuticle. Idiosomal setal pattern: 16A: 15B. All the dorsal setae except *J5* and *R5* lanceolate, seven of them such as *s6*, *Z3*, *Z4*, *Z5*, *S3*, *S4* and *S5* with serrations, *j5* minute. Length of setae: *j1* 29 (28–30), *j2* 26(26–29), *j3* 25 (23–25), *j4* 24 (24–25), *j5* 23(22–24), *z1* 23(21–23), *z2* 24(23–24), *z3* 24(22–24), *z4* 23(23–24), *z5* 24(23–24), *s2* 25(24–25), *s3* 25 (24–25), *s4* 26(24–26), *s5* 26 (25–26), *s6* 28 (26–29), *r3* 45(43–46), *J1* 24(24–25), *J2* 25(24–25), *J3* 25 (23–25), *J4* 24(24–25), *J5* 12(11–12), *Z1* 24(23–25), *Z2* 24 (23–24),

Z3 25(23–25), *Z4* 31(30–32), *Z5* 68(66–68), *S1* 29(28–30), *S2* 29(29–30), *S3* 31(29–30), *S4* 37(37–39), *S5* 43(42–43). Lateral cuticle with three pairs of setae; *r5* 24 (23–24), *R1* 21 (19–21), *R5* 20 (20–22).

Venter (Fig. 1.87 b, 1.92): Tritosternal base 14(13–15), lacinia 71(71–73) fused 47 µm length and free for less than half the total length (24(23–25)). The tritosternal base flanked by two narrow strips on either side above the sternal shield. Sternal shield 105 (101–105) long and 106(104–106) wide, concave posteriorly. Three pairs of sternal setae, simple and pointed; *st1* 30(29–30), *st2* 33(32–34), *st3* 35 (33–35), seta *st4* 31(30–32) located on metasternal shield. Genital shield 142(142–145) long and 103 (101–104) wide with seta *st5* 24 (23–25). Ventrianal shield 148 (147–149) long and 153 (151–154) wide, faintly ornamented, and with four pairs of setae; *JV1* 16 (14–16), *JV2* 14(14–16), *JV3* 15(14–15), *ZV2* 14(14–16) and paranal setae 13(12–15), postanal setae 32(32–34). *ZV1* 16 (15–17) located between genital and anal shield, *ZV3* 15 (14–16) and *JV4* 14 (13–15) lateral to the anal shield. Metapodal plates two pairs, located posterior to coxae IV, the anterior one being very narrow. Sperm access system (Fig. 1.89 e) with funnel shaped major duct 26 (24–27), heart shaped calyx 32 (30–34); minor duct well developed and expanded into a sac like structure with horned appendage 48(44–49).

Adult male:

Dorsum (Fig. 1.88 a): Length: 594(593–598), width: 257–264). Dorsal shield faintly ornamented. Chaetotaxy similar to that of female, but the length of setae different from that of the female: *j1* 25(24–26), *j2* 22 (21–23), *j3* 22(20–22), *j4* 21 (21–22), *j5* 23 (23–25), *z1* 21(20–22), *z2* 20(20–22), *z3* 21(20–22), *z4* 21(20–22), *z5* 21(20–21), *s2* 21(20–22), *s3* 21 (20–21), *s4* 22(21–23), *s5* 23 (21–23), *s6* 26 (25–27), *r3* 42(40–43), *J1* 22(21–23), *J2* 22(22–23), *J3* 22 (21–23), *J4* 23(20–23), *J5* 11(10–11), *Z1* 21(20–22), *Z2* 21 (21–22), *Z3* 23(22–25), *Z4* 28(27–30), *Z5* 64(63–66), *S1* 28(27–29), *S2* 28(27–30), *S3* 29(28–30), *S4* 31(30–33), *S5* 36(34–37). Lateral cuticle with three pairs of setae; *r5* 22 (21–23), *R1* 18 (17–20), *R5* 19 (19–20).

Venter (Fig. 1.88 b): Sternitigenital shield 204 (200–206) long and 88 (86–89) wide with five pairs of setae: *st1* 24 (22–24), *st2* 23 (20–23), *st3* 24 (23–24), *st4* 25 (24–25), *st5* 25 (23–26). Anal shield ornamented, 128(127–130) long and 142 (139–143) wide, with six pairs of setae, paranal setae *JV5* non serrated unlike that of female.

Gnathosoma: Fixed digit of female chelicerae with 11 teeth and movable digit with four teeth (Fig. 1.89.d). Subcapitulum (Fig. 1.89. a) with five rows of denticles, four pairs of simple and pointed setae. Gnathotectum (Fig. 1.89. b) broad without median projection. Fixed digit of male chelicerae with 11 teeth and movable digit unidentate (Fig. 1.89 c).

Legs (Fig. 1.90): Leg IV the longest, 335(332–339), leg III 324(319–329), leg II 260(253–262), leg I 329(325–330). Most of the setae smooth and pointed. Genu I-II-III-IV with 10-10-7-8; tibia I-II-III-IV with 10-8-6-7; tarsus: 18-9-8-11. Three long macrosetae on tibia, basitarsus and tarsus of fourth leg, longest one on the basitarsus.

Materials examined: Holotype: Adult ♀, from *B. tabaci* infested chilli leaves collected at Moolamkudam region (10°23'19.8"N 76°19'33.4"E), Thrissur, Dt., Kerala, India on 03.02.2020, Coll. Anjitha K Bhadrar.

Paratypes: 4♀♀ and 3♂♂ collected from the same plant.

Type deposition: All type specimens and specimens of all other species are presently deposited in the Division of Acarology, Dept. of Zoology, University of Calicut. The holotype will be transferred to the Zoological Survey of India, Calicut after publication.

Etymology: The species epithet '*moolamkudensis*' is derived from the name of the type locality Moolamkudam, of the species.

Remarks: Based on the key provided by Moraza & Lindquist (2018), the present species comes under the subgenus *Lasioseius* (*Lasioseius*) and species group *porulosus* with the following characters: dorsal shield flanked by only two or three pairs of setae, posterior dorsal shield with 16 pairs of setae, post humeral *r4* absent, tritosternal lacinia fused for more than half of the length, genua of legs I, II and III lacking one or two ventral setae. The genus *Lasioseius* includes 206 described species.

The species shares characteristics of *Lasioseius cuppa* described by Walter & Lindquist (1997) collected from Australian forest trees. Both of the species have similar number of setae on dorsal shield, three pairs of setae on lateral cuticle. Minor duct of sperm access system in both the species have a sac like and horned structure. Both the species have similar number of metapodal plates and four teeth on movable digit of chelicerae. However, the following character deviation of the present species

distinguishes it from *L. cuppa*, such as (1) majority of the dorsal setae lanceolate in *L.(L.) moolamkudensis* (tricarinate setae with serrate margins in *L.cuppa*), (2) fixed digit of chelicerae with 11 teeth (14–15 in *L.cuppa*), (3) sperm access system with heart shaped calyx (dome shaped in *L.cuppa*), (4) anterior epistome not denticulated (denticulate in *L.cuppa*), (5) postanal setae smooth (weakly barbed in *L.cuppa*) and (6) tarsus IV with seta longer than tibia (no setae longer than tibia in *L.cuppa*).

Superfamily : Dermanyssoidea Kolenati, 1815

Family : Laelapidae Berlese, 1892

Genus : *Laelaps* Koch, 1836

Generic diagnosis: Dorsal shield smooth or ornamented and with more than 30 pairs of setae. Gnathosomal and hypostomal setae mostly setaceous. Sternal shield with three pairs of sternal setae. Peritreme extending to the level of coxa I. Anal shield subtriangular.

***Laelaps* sp.**

(Fig. 1.93)

Colour: Transparent white

Measurements: Length: 770–775

Width: 435–440

Description

Deutonymph:

Dorsum (Fig. 1.93 a): Dorsal setae with distinct reticulations medially and decurrent lines along the lateral margin of the body. 40 pairs of dorsal setae, of which 23 pairs on the podosoma and 17 pairs on the opisthosoma, all setae smooth and pointed. Podosomal setae longer than the opisthosomal setae.

Venter (Fig. 1.93 b): Sternum and genital shield fused to form sterno-genital shield, which bears five pairs of setae. The posterior region of sterno-genital shield slightly concave and situated away from the ventri-anal shield. Preanal setae located on the

ventral integument, setae *Jv1* and *Jv2* inserted between the ventrianal shield and sterno-genital shield. Ventrianal shield carries the anal setae. Peritreme extending to the level of *j2*, stigmata located between coxae III and IV.

Gnathosoma: Chelicera with 10-11 teeth on the movable digit and a single tooth on the fixed digit.

Legs: Legs I-IV with well developed ambulacra. Macrosetae present on femur, basitarsus and tarsus.

Adult: Not recovered during sampling.

Materials examined: Three deutonymphs, from *O. rhinoceros* collected at Manissery (10°46'43.1"N 76°20'26.2"E), Palakkad Dt., Kerala, India on 02/11/2018, Coll. Anjitha K Bhadrar.

Host range: rodents, ants, higher mammals

Remarks: The genus was reported to be associated with rodents and phoretic on insects. The literature available on deutonymphal stages of *Laelaps* is scanty and hence a comparative study is excluded.

Genus : *Hypoaspis* G. Canestrini, 1884

Generic diagnosis: Dorsal shield entire, oval and with more than 34-40 pairs of setae. Sternal shield of female with three pairs of setae. Peritrematal shields extend beyond coxa I. Genital shield tongue shaped. Tritosternum well developed with two pilose laciniae. Pilus dentilis short and setiform. Spermatodactyl grooved and free distally. Sternal, genital, anal and endopodal shields of male fused to form holovenral shield.

***Hypoaspis heselhoui* Oudemans, 1912**

(Fig. 1.94)

Colour: Tan

Measurements: Length: 448–453

Width: 262–268

Description

Adult female:

Dorsum (Fig. 1.94 a): Dorsal shield smooth carrying 41 pairs of setae, most of which smooth and needle like. Setal formula 25A: 16B. Seta *jl* lanceolate, seta *r6* stout and small. Tritosternal lacinia bilobed and pilose.

Venter (Fig. 1.94 b): Sternum slightly concave at the posterior and concave at the anterior region. Three pairs of setae on the sternum, seta *st4* located on small metasternal plate. Genital shield with setae *st5*, placed far distinct from the anal shield. Anal shield subtriangular with needle like preanal and paraanal setae. Two pairs of setae, *Jv1* and *Jv2* between genital and anal shield. Tectum with a median triangular mucron. Subcapitulum with seven rows of denticles.

Gnathosoma: Fixed digit of chelicerae with seven teeth and movable digit of chelicerae with two teeth.

Legs: Femur and genu segments of leg II with six needle like setae each. Femur and genu of leg IV with four and five setae respectively.

Male: Not recovered during sampling.

Materials examined: 2 ♀♀, from *C. molossus* collected at Killikavu (10°45'43.5"N 76°19'21.5"E), Palakkad Dt., Kerala, India on 09.06.2018, Coll. Anjitha K Bhadrn.

Habitat range: Leaf litter, soil and mammals.

Remarks: The present specimens possess several features similar to *H. heselhousi* Oudemans, 1912. However, it differs from *H. heselhousi* in the following characters: dorsal shield is oval (broader towards the posterior side of body in *H. heselhousi*); setae *jl* and *r6* dissimilar in shape compared to all other dorsal setae in the present species (all dorsal setae similar in *H. heselhousi*). Considering the similarities in majority of features, the present specimens were assigned to the above taxon. This forms the first report of the species from dung beetle.

Hypoaspis sardous (Canestrini, 1884)

(Fig. 1.95)

Colour: Tan

Measurements: Length: 535–548

Width: 365–372

Description

Adult female:

Dorsum (Fig. 1.95 a): Dorsal shield smooth, without ornamentations. Dorsal shield carries 39 pairs of smooth and tapering setae, some of the podosomal setae longer. Setal formula follows 23A: 16B. Seta *r4* the longest among all the dorsal setae. Tritosternal lacinia fused about half their length, with pilose lacinia.

Venter (Fig. 1.95 b): Sternal shield slightly concave at the posterior and anterior and with three pairs of long and needle like setae. Seta *st4* located on the metasternal plate. Genital shield broad, tongue shaped and reaching to the ventrianal shield, carrying with one pair of seta, *st5*. Ventrianal shield tongue shaped with needle like paranal and postanal setae. A pair of setae placed between genital shield and ventrianal shield. Peritreme long and extending to the level of *j2*, stigmata between coxae III and IV. Peritrematal shield broad and extending to the level of coxa IV. Tectum arch shaped and irregularly denticulated. Deutosternum with six rows of denticles and subcapitulum with four pairs of setae.

Gnathosoma: Fixed digit of chelicerae with two teeth and movable digit unidentate.

Leg: Femur and genu of leg II with 10 setae each. Femur and genu of leg IV with six and eight setae respectively.

Male: Not recovered during sampling.

Materials examined: 4 ♀♀ from *O. rhinoceros* collected at Thachudaparambu (10°18'34.7"N 76°19'21.1"E), Thrissur Dt. on 26.07.2017; 2 ♀♀ from *O. rhinoceros* collected at Manissery (10°46'43.1"N 76°20'26.2"E), Palakkad Dt., Kerala, India on 16.08.2018, Coll. Anjitha K Bhadrar.

Habitat range: Nests of arthropods and insects.

Remarks: The present specimens resemble the species, *H. sardous* described by Berlese (1911) in all diagnostic features, except in the following characters: Podosomal setae like *z1*, *j2*, *j3*, *z4*, *s3*, *r2*, *r4* longer than all other dorsal setae in the present species but all the dorsal setae are of similar length in *H. sardous*. Seta *z4* exceeds the posterior body margin in the present specimens but not reaching the posterior body margin in *H. sardous*. This forms the first report of the occurrence of this species from India.

***Hypoaspis subterranea* Willman, 1952**

(Fig. 1.96)

Colour: Brown

Measurements: Length: 760–768

Width: 610–615

Description

Adult female:

Dorsum (Fig. 1.96 a): Dorsal shield smooth and possesses 33 pairs of smooth and needle like setae, lateral pairs being larger than the rest of the setae. Setal formula 18A: 15B. Seta *j1* stout and broad. Tritosternal base triangular and exceeding the length of pilose lacinia.

Venter (Fig. 1.96 b): Sternal shield slightly concave at the posterior margin, with two pairs of long smooth, tapering setae. The lateral region of sternum with distinct punctation. Setae *st3*, *st4* and *st5* kukri knife shaped. Genital shield not broader than the anal shield. Anal shield subquadrate, and carries the paranal and postanal setae. Setae *Jv1* and *Jv2* placed between the genital and anal shields. Peritreme long and exceeding beyond the seta *r1*, stigmata placed between coxae III and IV. Area between the body margin and the peritrematal shield granulated in appearance.

Gnathosoma: Tectum arch shaped and serrated. Deutosternum with five rows of denticles, each row with more than six teeth. Subcapitulum with four pairs of setae. Fixed digit of chelicerae multidentate and movable digit unidentate.

Legs: Leg II with spine like setae. Femur and genu segments of leg II with eight and six setae respectively, most of which being spine like. Femur and genu of leg IV with three and five needle like setae respectively.

Male: Not recovered during sampling.

Materials examined: 2 ♀♀ from *C. repertus* collected at Panamanna (10°48'34.9"N 76°21'00.2"E), Palakkad Dt., Kerala, India on 19.07.2018, Coll. Anjitha K Bhadrans.

Host range: coprophagous beetles

Remarks: The specimen is similar to *H. subterranea* Willman, 1952 in all characters. This forms the first report of the species from India.

Genus : *Dinogamasus* Kramer, 1898

Generic diagnosis: Peritreme very distinct and definite in most of the species but may be quite indistinct in some species due to poor chitinization. Fixed digit is often shorter than the movable digit. One pair of claws present on all pretarsi. Certain hairs on legs I and II modified to blunt cones.

***Dinogamasus* sp.**

(Fig. 1.97)

Colour: Transparent -white

Measurements: Length: 583–590

Width: 316–320

Description

Deutonymph:

Dorsum (Fig. 1.97 a): Dorsal shield ornamented with punctation and bears 42 pairs of setae, of which 20 pairs unilaterally serrated while the remaining 22 pairs short, smooth and pointed.

Venter (Fig. 1.97 b): Sternal shield with five pairs of setae, the posteriormost pair, *st5* longer than all others. Ventrianal shield oval, with two pairs of preanal setae.

Gnathosoma: Chelicera developed but teeth not distinctly visible on fixed and movable digits.

Legs: Legs II-IV with well developed ambulacra on the tip of their tarsi. All leg segments with short and simple setae.

Adult: Not recovered during sampling.

Materials examined: Two deutonymphs, from the prosternum of *R. ferrugineus*, collected at Thachudaparambu (10°18'34.7"N 76°19'21.1"E), Thrissur Dt., Kerala, India on 19.09.2018, Coll. Anjitha K Bhadrar.

Host range: Acarinaria of bees, *Xylocopa*.

Remarks: The members (mostly females) of the genus *Dinogamasus* are constant associates of carpenter bees. Presently no data are available on the deutonymphs of *Dinogamasus* and hence no comparison was made during the study. This forms the first report of the genus showing association with *R. ferrugineus*.

Superorder : Acariformes Zakhvatkin, 1952

Order : Trombidiformes Reuter, 1909

Suborder : Prostigmata Kramer, 1877

Superfamily : Bdelloidea Duges, 1834

Family : Cunaxidae Thor, 1902

Genus : *Cunaxa* Von Heyden, 1826

Generic diagnosis: Heavily sclerotised body with distinct propodosoma and hysterosoma. Propodosoma and hysterosoma with or without shield. Palpi five segmented with stout spine like setae. Tarsi I-IV long and slender.

***Cunaxa anomala* Khaustov & Kuznetsov, 1998**

(Fig. 1.98)

Colour: Red

Measurements: Length: 470–485

Width: 235–240

Description

Adult female:

Dorsum (Fig. 1.98 a): Dorsum ornamented, with striations and bears 11 pairs of setae. Propodosomal shield punctated, and possesses setose sensilla, *at* (156–159) and *pt*(192–197). Seta *mps* present on the propodosomal shield smooth, seta *lps* absent. Hysterosoma bears the setae *c2*, *c1-h1*. Anal region with two pairs of setae, *ps1* and *ps2*.

Venter (Fig. 1.98 b): Ventral region with papillate striations. Coxae well developed. Genital valves with four pairs of setae (*g1-g4*), all equally long and inserted equidistantly. One pair of aggenital seta, *ag* present lateral to genital valves. Propodogastral setae, *ppgs* present near coxa II. Hysterogastral setae four pairs present between coxa III and genital valves.

Gnathosoma: Gnathosoma with four pairs of *hg* setae and two pairs of ventral adoral setae. Palp five jointed. Cheliceral seta present on the long chelicera.

Leg chaetotaxy: Co I-IV, 3-1-3-2; Tr I-IV, 1-1-3-0; Fe I-IV, 4-2-3-1; Ge I-IV, 9-7-6-6, Ti I-IV 7-6-6-10, Ta I-IV 32-25-24-20.

Male: Not recovered during sampling.

Materials examined: 2 ♀♀ from *B. tabaci* infested chilli leaves collected at V. R. puram region (10°18'44.4"N 76°19'19.4"E), Thrissur Dt., Kerala, India on 12.02.2020, Coll. Anjitha K Bhadrán.

Habitat range: Fruit plant, *Diaspyros kaki*

Remarks: The specimen examined resembles *C.anomala* described by Khaustov & Kuznetsov, 1998 from Crimea. This forms the first report of the species from chilli.

***Cunaxa heterostriata* Khaustov & Kuznetsov, 1998**

(Fig. 1.99)

Colour: Red

Measurements: Length: 545–550

Width: 232–235

Description

Adult female:

Dorsum (Fig. 1.99 a): Dorsal shield striated, with 11 pairs of setae. Propodosomal shield smooth, with setose sensilla, *at* (163–166) and *pt*(258–265). Setae *mps* and *lps* present, both smooth, the latter being smaller than the former. Hysterosoma without any shield, bearing the setae *c2*, *c1-h1*. Anal region with one pair of setae, *ps1*.

Venter (Fig. 1.99 b): Papillate striations present on the ventral part. Legs with well developed coxae. Genital valves with four pairs of equally long setae (*g1-g4*), *g1* and *g4* displaced laterally from *g2* and *g3*. One pair of aggenital seta, *ag* present lateral to genital valves. Propodogastral setae, *ppgs* situated adjacent to coxa II. Three pairs of hystergastral setae present between coxa III and genital valves.

Gnathosoma: Gnathosoma with four pairs of *hg* setae and two pairs of ventral adoral setae. Palp five jointed. Chelicera long with one cheliceral seta.

Leg: Leg chaetotaxy: Co I-IV, 3-1-3-2; Tr I-IV, 1-1-2-1; Fe I-IV, 4-2-3-1; Ge I-IV, 9-7-6-6, Ti I-IV 7-6-6-10, Ta I-IV 32-25-24-22.

Male: Not recovered during sampling.

Materials examined: 2 ♀♀ from *B. tabaci* infested chilli leaves collected at V. R. puram region (10°18'44.4"N 76°19'19.4"E), Thrissur Dt., Kerala, India on 12.02.2020, Coll. Anjitha K Bhadrn.

Habitat range: lichen

Remarks: The specimen examined resembles the species, *C. heterostriata* described by Khaustov & Kuznetsov, 1998 from Crimea. This forms the first record of the species from chilli.

Superfamily : Erythraeoidea Grandjean, 1947

Family : Erythraeidae Oudemans, 1992

Genus : *Leptus* Latreille, 1795

Generic diagnosis: Idiosoma oval in shape. Scutum present dorsally on idiosoma and variably punctated. Two pairs of sensilla and two pairs of scutula present on the scutum. Dorsal body setae mostly with dense setules. A pair of eyes present on the scutal shield. Palp tarsus with eight setae. Tarsi I-III with a pair of claws.

***Leptus treati* Welbourn & Jennings, 1991**

(Fig. 1.100)

Colour: Blood red

Measurements: Length: 450–480

Width: 230–245

Description

Larva:

Dorsum (Fig. 1.100 a): Dorsum smooth, with thick and barbed setae. Prodorsal shield with four pair of setae; *v1* and *sc2* thin and barbed, *v2* and *sc1* thick and serrated. An eyespot present lateral to the prodorsal shield. Idiosoma bears 73 barbed setae of similar size and thickness. Three pairs of cupules, *ia*, *im* and *ip* present on the idiosoma.

Venter (Fig. 1.100 b): Ventral side smooth with 22 pairs of barbed setae. One pair of setae between coxal fields I and II, two pairs of setae between coxal field III.

Gnathosoma: Gnathosoma triangular with well developed palp. Palp with one barbed setae each on femur, genu and tarsus, being terminated by a claw.

Legs: Chaetotaxy of: Leg I: Co 1- Tr 1- Fe 7- Ge 8 (1)- Ti 14 (2)- Ta 24 (1) and a famulus ε; Leg II: Co1- Tr 1- Fe 7- Ge 8- Ti 15 (2); Leg III: : Co 1- Tr 1- Fe 6- Ge 8- Ti 15 (1)- Ta 23 (1).

Adult: Not recovered during sampling.

Materials examined: 5 larvae from *Oxya hyla* collected at Panamanna (10°48'34.9"N 76°21'00.2"E), Palakkad Dt. on 18.11.2018; 2 larvae from *O. hyla* collected at

Kuzhikkani (10°22'15.3"N 76°19'15.1"E), Thrissur Dt., Kerala, India on 23.02.02019, Coll. Anjitha K Bhadran.

Host range: *Choristoneura fumijerana* (eggs).

Remarks: The specimen examined resembles the species, *Leptus treati* described by Welbourn and Jennings, 1991 from USA. This forms the first report on the association of the species with *O.hyla*.

Superfamily : Trombidioidea Leach, 1815

Family : Trombidiidae Leach, 1815

Genus : *Neosilphitrombium* Fain, 1992

Generic diagnosis: Larva possesses two median prodorsal idiosomal shields, the anterior one with eight setae and posterior shield with two setae. Legs with six segments. Tarsal claws 3-3-3. Uropore present on gnathosoma but lacks a chitinous ring. Thick bifid spines present on coxae I-III and on anterior scutum.

Neosilphitrombium gratum Fain, 1992

(Fig. 1.101)

Colour: Orange

Measurements: Length: 980–1020

Width: 550–565

Description

Larva:

Dorsum (Fig. 101 a): Anterior and posterior scutum punctate, and without a nasus at the anterior region. Scutum bears four pairs of setae; AM thin and barbed, AL forked and short, PL and QL barbed, the former shorter than the latter. Scutellum punctated and bears a pair of barbed setae. A pair of eyes placed lateral to the scutum. 16 pairs of weakly barbed setae present, three pairs situated on the propodonotum, arranged in two rows and 13 pairs on the hysteronotum, arranged in six rows (4-8-8-2-2-2).

Venter (Fig. 101 b): A pair of setae present between coxae III. Sternal setae absent. Opisthogaster with 26 thin and weakly barbed setae.

Gnathosoma: Gnathosoma short with well developed palp and palpal setae. Mouth without a chitinous ring. Uropore present.

Legs: Coxae I and II with three pairs of forked setae and one pair of tapering and barbed setae on coxae II. Coxae III with two pairs of forked setae. All tarsi ending with sharp and paired claws. Chaetotaxy of : Leg I: Tr 1- Fe 3- Ge 2(3)- Ti 3(3)- Ta 6(3), Leg II: Tr 1- Fe 3- Ge 2(1)- Ti 1(2)- Ta 6(2), Leg III: Tr 1- Fe 2- Ge 1(1)- Ti 3- Ta 6.

Adult: Not recovered while sampling.

Materials examined: 4 larvae, from *B.rufomaculata*, collected at Vattamkulam (10°47'19.4"N 76°01'35.0"E), Malappuram Dt., Kerala, India on 19.08.2018, Coll. Anjitha K Bhadran.

Host range: carrion beetle.

Remarks: The specimen examined closely resembles the species, *N.gratum* described by Fain, 1992 from Africa. This forms the first report of the species from *Batocera rufomaculata*.

Superfamily : Cheyletoidea Leach, 1815

Family : Cheyletidae Leach, 1815

Genus : *Cheyletus* Latreille, 1796

Generic diagnosis: Propodosomal shield of females with one pair of setae. Dorsomedian setae absent and if present, it is abnormal. Neotrichial setae present. Dorsal shield with ornamentation. Femur IV with one seta. Dorsal seta of palp femur and genu lanceolate or fan like.

***Cheyletus kuznetsovi* Bochkov & Khaustov, 1999**

(Fig. 1.102)

Colour: Dark orange

Measurements: Length: 230–260

Width: 142–150

Description

Adult female:

Dorsum (Fig. 1.102 a): Dorsum with hexagonal ornamentations. Idiosomal dorsum with two separate shields. Eyes absent. Propodosomal shield trapezoidal, wider than long, with one pair of median seta. Four pairs of fan like setae on the lateral margin of the propodosoma; *vi*, *ve*, *sci* and *sce*. Hysterosomal shield length almost equal to width, with three pairs of median setae.

Venter (Fig. 1.102 b): Ventral surface of idiosoma striate, with three pairs of intercoxal setae. Genital area with two pairs of genital setae and three pairs of pregenital setae. Anal setae three pairs. All ventral setae fan like.

Gnathosoma: Gnathosoma with one pair of adoral and supracoxal setae each on the dorsum and subcapitular setae on the venter.

Legs: All legs with fan like setae.

Male: Not recovered while sampling.

Materials examined: 3 ♀♀ from *Gonocephalus* sp. collected at Manissery (10°46'43.1"N 76°20'26.2"E), Palakkad Dt., Kerala, India on 21.09.2017, Coll. Anjitha K Bhadrar.

Habitat range: stored products.

Remarks: The present specimens resemble *C.kuznetsovi* described by Bochkov & Khaustov, 1999. This forms the first report of the species from *Gonocephalus* sp.

Superfamily : Tarsocheyloidea Atyeo & Baker, 1964

Family : Tarsocheylidae Berlese, 1904

Genus : *Hoplocheylus* Atyeo & Baker, 1964

Generic diagnosis: Palp tibiotarsus with a terminal claw bearing a subterminal process, one ventral solenidion, three tactile setae, three eupathidia. The eupathidia sometimes represented by a duplex setae and two subterminal processes, setigenous, flange-like or spine like. One pair of spine like papillae present on hypostome.

***Hoplocheylus longispinus* Atyeo & Baker, 1964**

(Fig. 1.103)

Colour: Creamy white

Measurements: Length: 420–450

Width: 135–146

Description

Adult female:

Dorsum (Fig. 1.103 a): Dorsal shield with *C*, *D*, *EF* and *H* segments. Dorsal body surface ornamented with striations, except for the dorsal shields. Prodorsal shield smooth with straight anterior margin. All dorsal idiosomal setae pointed and smooth. Trichobothria clavate and smooth. *C* segment with two pairs of setae, *D* segment with one pair of seta, two pairs of setae each on segments *EF* and *H*.

Venter (Fig. 1.103 b): A rectangular smooth plate present between coxae of legs II and III. Four pairs of genital setae present lateral to the triangular genital opening. Short and pointed setae present at the coxal fields.

Gnathosoma: Femur and genu of gnathosomal palpus fused. Fused tibiotarsus with six setae, one solenidion and two spines on anterior tarsus. Chelicera longitudinally fused.

Legs: Tarsi with a pair of hooked claws. Tibia I with four setae and two solenidia, $\phi 1$ and $\phi 2$. Tarsus I with one solenidion ω and 11 smooth and pointed setae.

Male: Not recovered during sampling.

Materials examined: 4♀♀ from the abdomen of *Gonocephalus* sp., collected at V. R. Puram (10°18'44.4"N 76°19'19.4"E), Thrissur Dt., Kerala, India on 06.07.2017, Coll. Anjitha. K. Bhadrán.

Habitat range: Moss and rotten wood.

Remarks: The present specimens agree with the species, *H. longispinus* described by Atyeo & Baker, 1964 from Michigan in all morphological features. This is reported for the first time from *Gonocephalus* sp.

***Hoplocheylus zanzibariensis* Khaustov & Ermilov, 2018**

(Fig. 1.104)

Colour: Creamy white

Measurements: Length: 375–390

Width: 130–135

Description

Adult female:

Dorsum (Fig. 1.104 a): Dorsum smooth with distinct striations. A characteristic U shaped apodeme present at the posterior region of tergite H. All dorsal idiosomal setae pointed, some being smooth (*v1*, *v2*, *sc2*, *c1*, *c2*) and some barbed at the distal half (*d*, *e*, *f*, *h1*, *h2*, *ps1*). Prodorsal sclerite with three setae; *v1*, *v2* and *sc2* and a clavate trichobothria. Tergite C with two setae; *c1* and *c2*, tergite D with a single seta, *d*; tergite EF with two setae, *e* and *f*; tergite H with setae *h1*, *h2* and *ps1*. Three cupules of circular shape, *im*, *ip* and *ih* present, *im* and *ip* placed on the tergite EF and *ih* located on lateral margin of tergite H.

Venter (Fig. 1.104 b): Apodemes I- IV and genital apodeme well developed. Coxal field I with four setae *1a*, *1b*, *1c* and *1d*; coxal field II with three setae *2a*, *2b* and *2c*; coxal field III with three setae *3a*, *3b* and *3c* and coxal field IV with two setae *4a* and *4b*. Aggenital setae *ag1*, *ag2* and *ag3* present posterior to coxal field IV. Genital setae three pairs, *g1*, *g2* and *g3*. Setae *ps2* and *ps3* located adjacent to U shaped apodeme located at the posterior part of the idiosoma.

Gnathosoma: Palp four segmented. All gnathosomal setae smooth. Median apodeme vestigial at the dorsal side. Gnathosomal setae four pairs; *cha*, *chb*, *m* and *n*, postpalpal setae peg like.

Legs: Legs II-IV ending with an empodium. Legs I-IV with well developed paired claws. Chaetotaxy of: Leg I: Tr 1- Fe 5- Ge 5- Ti 6(2)- Ta 14 (2), Leg II: Tr 1- Fe 3- Ge 4- Ti 5- Ta 7 (1), Leg III: Tr 2- Fe 2- Ge 3- Ti 5(1)- Ta 7, Leg IV: Tr 1- Fe 2- Ge 2- Ti 5- Ta 6.

Male: Not recovered during sampling.

Materials examined: 5 ♀♀, from *O. philemon*, collected at V.R. Puram (10°18'44.4"N 76°19'19.4"E), Thrissur Dt., Kerala, India on 22.10.2019, Coll. Anjitha K Bhadran.

Habitat range: litter.

Remarks: The present specimens exhibit great similarity to the species, *H. zanzibarensis* described by Khaustov & Ermilov, 2018 from Tanzania in all morphological features. This forms the first report of occurrence of this species on dung beetles.

Superfamily : Dolichocyboidea Mahunka, 1970

Family : Dolichocybidae Mahunka, 1970

Genus : *Pavania* Lombardini, 1949

Generic description: Prodorsal shield with three pairs of setae. All tergites either smooth or with dimples. Tergite EF with characteristic dimples. Dorsal setae either smooth or weakly barbed. Ventral setae smooth. Apodemes I and IV well developed joined with prosternal apodeme.

***Pavania foliata* Khaustov & Frolov, 2020**

(Fig. 1.105)

Colour: Creamy white

Measurements: Length: 156 (150–158)

Width: 105 (98–106)

Description

Adult female:

Dorsum (Fig. 1.105 a): Dorsum with five shields/ tergites; PdS, C, D, EF and H. All the dorsal setae smooth and needle like. Dorsal tergite PdS with three pairs of setae (*v1*, *v2* and *sc2*) and a pair of trichobothria (*sc1*), tergite C with two pairs of setae (*c1* and *c2*), D with two pairs of setae (*d1* and *d2*), EF with two pairs of setae (*e* and *f*) and H with a single pair of setae (*h*).

Venter (Fig. 1.105 b): Venter with well developed apodemes, *ap1*, *ap2*, *ap3* and *ap4*. Presternal apodemes (*appr*), sejugal apodemes (*apsej*) and poststernal apodemes (*appo*) visible. All the ventral setae smooth and needle like. Seta *h2* long and curved.

Gnathosoma: Gnathosomal capsule without dorsal median apodeme and three pairs of setae.

Legs: Legs I-IV with well developed ambulacra. Chaetotaxy of legs, Leg I : Tr 0- Fe 1- Ge 3- Ti 4- Ta 13; leg II Tr 1- Fe 3- Ge 2- Ti 5- Ta 6; leg III Tr 1- Fe 2- Ge 2- Ti 4- Ta 6; leg IV Co 1- Tr 0- Fe 2- Ge 1- Ti 3- Ta 6. Seta *d* on femur III leaf shaped. Solenidiotaxy: Tarsus I with fingershaped ω and clavate ϕ_1 and ϕ_2 . Tibia II with small and finger shaped ϕ and clavate ω . Tibia III with finger shaped ϕ .

Male: Not recovered while sampling.

Materials examined: 3 ♀♀ from *C. molossus* collected at C.U. Campus (11°08'01.9"N 75°53'26.3"E), Kerala, India, on 28/10/2018, Coll. Anjitha K Bhadrn.

Host range: *Scarabaeus typhon*

Remarks: The specimen examined is similar to *P.foliata* described by Khaustov and Frolov, 2020 from Russia in all morphological features. This forms the first report of the species from *C. molossus*.

Superfamily : Pygmephoroidae Cross, 1965

Family : Microdispidae Cross, 1965

Genus : Premicrodispus Cross, 1965

Generic diagnosis: Prodorsal shield with distinct tracheal system and stigmata. Dorsal tergites mostly smooth, bearing one pair of setae and one pair of trichobothridia. Tergites C, EF and H possess two pairs of setae while tergite D bears

one pair of setae. Coxal fields I, II and IV with two pairs of setae. Pharyngeal system with three pumps.

***Premicrodispus paramaevi* Hosseininaveh & Hajiqanbar, 2014**

(Fig. 1.106)

Colour: Transparent- white

Measurements: Length: 180–185

Width: 90–95

Description

Adult female:

Dorsum (Fig. 1.106 a): Dorsal shield distinctly divided into four segments; *C*, *D*, *EF* and *H*. Prodorsal shield with one pair of trichobothria and one pair of seta. Tracheal system and an elongate stigma distinct. Tergite *C* with two pairs of setae, *c1* and *c2*; tergite *D* with one pair of seta, *d* and cupule *ia*; tergite *EF* with two pairs of setae, *e* and *f*; tergite *H* with two pairs of setae, *h1* and *h2* and a pair of cupule, *ih*.

Venter (Fig. 1.106 b): Ventral shields smooth. Apodemes I and II reaching presternal apodeme. Apodeme III extending beyond *3a*, apodeme IV extending beyond *3b*. Coxal field I with two pairs of setae, *1a* and *1b*; coxal field II with two pairs of setae, *2a* and *2b*; coxal field III with three pairs of setae, *3a*, *3b* and *3c*; coxal field IV with three pairs of setae, *4a*, *4b* and *4c*. Pseudoanal segment with two pairs of setae, *ps1* and *ps3*.

Gnathosoma: Cheliceral setae, *ch1* and *ch2* present dorsally. Palp with two pairs of setae, *dGe* and *dFe*.

Leg: Leg chaetotaxy: Leg I: Tr 1- Fe 3- Ge 4- Ti+ Ta 15 (4); Leg II: Tr 1- Fe 3- Ge 3- Ti 4 (1)- Ta 6 (1); Leg III: Tr 1- Fe 2- Ge 2- Ti 4 (1)- Ta 6; Leg IV: Tr 1- Fe 2- Ge 1- Ti 4 (1)- Ta 6.

Male: Not recovered during sampling.

Materials examined: 6♀♀ from *O. feae* collected at Kanniyampuram (10°46'37.4"N 76°21'01.2"E), Palakkad Dt., Kerala, India on 21.06.2017, Coll. Anjitha K Bhadrn.

Host range: *Lucanus ibericus*

Remarks: The specimens examined possess morphological similarity to *P. paramaevi* described by Hosseininaveh and Hajiqanbar, 2014 from Iran except in the length of some of the leg setae. This is the first report of the species from termites.

Family : **Pygmephoridae**

Genus : ***Pygmephorellus* Cross & Moser, 1971**

Generic diagnosis: Tibia and tarsus of leg I fused. Coxal fields I and II with three and two pairs of setae respectively. Setae on prodorsum simple. Tarsi II-IV with well developed empodia. Genua I and II with four and three setae respectively.

***Pygmephorellus indicus* sp. nov.**

(Fig. 1.107-1.108)

Colour: Creamy- white

Measurements: Length: 165 (160–168)

Width : 325 (320–330)

Description

Adult female:

Dorsum (Fig. 1.107 a): Length of idiosoma 165 (160–168), width 325 (320–330). Dorsum with five shields/ tergites; PdS 26(25–38), C 43 (33–45), D 62(54–65), EF 22(16–24) and H 14(12–14). All the dorsal setae weakly barbed. Dorsal tergite PdS with three pairs of setae (*v1*, *v2* and *sc2*) and one pair of trichobothria (*sc1*), tergite C with two (*c1* and *c2*), D with one (*d*), EF with two (*e* and *f*) and H with two (*h1* and *h2*) pairs of setae. Setae *Sc2*, *c1*, *c2*, *d*, *e*, *f*, *h1* and *h2* with serrations. Three cupules *ia*, *im* and *ih* present on tergite D, EF and H respectively. Length of setae: *v1* 19(17–19), *v2* 10(9–11), *sc1* 14(13–16), *sc2* 56(49–57), *c1* 40(39–41), *c2* 51(49–53), *d* 42(40–44), *e* 19(17–21), *f* 43(41–44), *h1* 40(39–42), *h2* 22(20–23).

Venter (Fig. 1.107 b): Venter with well developed apodemes, *ap1*, *ap2*, *ap3* and *ap4*. Presternal apodemes (*appr*), sejugal apodemes (*apsej*) and poststernal apodemes (*appo*) visible. All the ventral setae smooth and needle like. Length of ventral setae:

m 9(9–11), *la* 14(12–15), *lb* 14(12–14), *lc* 14 (12–14), *2a* 15(14–16), *2c* 14(12–15), *3a* 16(15–18), *3b* 16(14–17), *3c* 15(13–16), *4a* 15(13–15), *4b* 15(14–16), *4c* 14(12–15), *ps1-2* 11(9–11), *ps3* 17(16–17).

Gnathosoma (Fig. 1.108 d): Gnathosomal capsule without dorsal median apodeme. All gnathosomal setae needle like. Setae *ch1* 6(4–6), *ch2* 7(6–7), *dGe* 6 (5–7), *dFe* 7(6–7).

Legs (Fig. 1.108 a, b, c and e): Leg I ends with a blunt claw, legs II–IV with well developed ambulacra. Chaetotaxy of Leg I : Tr 0- Fe 1- Ge 4- Ti+Ta 19; Tr 1- Fe 3- Ge 1- Ti 4- Ta 6; Tr 1- Fe 2- Ge 2- Ti 4- Ta 6; Tr 1- Fe 2- Ge 1- Ti 4- Ta 6. Solenidiotaxy: Tarsus I with clavate shaped ω_1 and φ_1 , finger shaped ω_2 and φ_2 . φ on tibia II and III small and finger shaped.

Male: Not recovered while sampling.

Holotype: Adult ♀, from the body of *C. repertus* at Kothayur region (latitude 10°46'60.0"N and 76°20'26.5"E longitude), Palakkad Dt., Kerala, India on 19.11.2018, coll. Anjitha K Bhadrans.

Paratypes: 3 ♀♀, from the body of *C. repertus* at Kothayur region (latitude 10°46'60.0"N and 76°20'26.5"E longitude), Palakkad Dt., Kerala, India on 19.11.2018, coll. Anjitha K Bhadrans.

Type deposition: All type specimens and specimens of all other species are presently deposited in the Division of Acarology, Dept. of Zoology, University of Calicut. The holotype will be transferred to the Zoological Survey of India, Calicut after publication.

Etymology: The specific epithet 'indicus' is derived from the name of the country 'India' which encompasses the type locality.

Remarks: The genus *Pygmephorellus* Cross & Moser, 1971 includes three species viz. *P. ceratophyi* (Krczal 1959) and *P. punctatus* Khaustov, 2005 and *P. tauricus* Khaustov, 2007. The present species forms the fourth addition to the genus. The species is similar to *P. tauricus* Khaustov, 2007 described from Crimea in characters like dorsal and ventral chaetotaxy, form of setae and leg characters. The species *P. indicus* sp. nov. differs from *P. tauricus* Khaustov, 2007 in the following characters;

Dorsal tergite with dimples forming a characteristic shape (all dorsal tergites with dimples distributed mainly at the central part in *P. tauricus*); seta *c1* extending beyond the tergite *C* (seta *c1* does not reach the posterior margin of tergite *C* in *P. tauricus*); considerable distance between the bases of setae *h1* and *h2* (distance between the setae *h1* and *h2* very short in *P. tauricus*); setae *d*, *e* and *f* placed close to the anterior margin of tergites *D* and *EF* respectively (setae *d*, *e* and *f* placed at the middle portion of tergites in *P. tauricus*); setae *e* and *h2* serrated (setae *e* and *h2* smooth in *P. tauricus*); apodeme 3 well developed (apodeme 3 weakly developed in *P. tauricus*); seta *dFe* smooth (seta *dFe* sickle like and thickened in *P. tauricus*).

Superfamily : Tarsonemoidea Canestrini&Fanzago, 1877

Family : Tarsonemidae Kramer, 1877

Genus : Steneotarsonemus Beer, 1954

Generic diagnosis: Females with elongate body. Legs I and II widely separated from III and IV. Females with two pairs of propodosomal setae. Males with four pairs of propodosomal setae and femur IV with a flang like process.

***Steneotarsonemus brasiliensis* Flechtmann, 1993**

(Fig. 1.109)

Colour: Transparent- white

Measurements: Length: 320–335

Width: 165–170

Description

Adult female:

Dorsum (Fig. 1.109 a): Dorsal shield elongate and smooth. Prodorsal shield subrectangular, bearing three pairs of setae, *vi*, *sc2* and the clavate trichobothria *sc1*. Four tergites, *C*, *D*, *EF* and *H* distinguishable. Tergite *C* with two pairs of setae, *c1* and *c2*; tergite *D* with one pair of seta, *d*; tergite *EF* with two pairs of setae, *e* and *f*; tergite *H* with one pair of setae, *h*, the latter barbed, all others smooth. Dorsum with two pairs of cupule, *ia* and *ih*.

Venter (Fig. 1.109 b): Ventral shields smooth. Apodeme I fused to anteromedian apodeme, together extending posteriorly, slightly beyond apodeme II. Apodeme II not touching the transverse sejugal apodeme. Transverse apodeme vestigial, present only medially. A subrectangular ventrocaudal lobe situated between legs IV. Coxal region I, II, III and IV with setae *1a*, *2a*, *3a* and *4a* respectively.

Gnathosoma: Palpi short and directed anteriorly with a pair of anteroventral setae. Cheliceral stylets short.

Legs: Leg III longer than legs I and II. Chaetotaxy of : Leg I: Fe 4- Ge 3- Ti+Ta 12 (2); Leg II: Fe3- Ge 3- Ti 4- Ta 5 (3); Leg III: Fe+ Ge 4- Ti 4- Ta 5. Leg IV with fused segments, and with two pairs of long terminal setae.

Male: Not recovered during sampling.

Materials examined: 2♀♀ from *O.hyla* collected at Pattambi (10°48'41.7"N 76°10'36.1"E), Palakkad Dt., Kerala, India on 26.02.2019, Coll. Anjitha K Bhadrn.

Habitat range: *Saccharum officinarum*

Remarks: The specimen examined is morphologically similar to *S.brasiliensis* described by Flechtman, 1993 from Brazil. This forms the first report of the occurrence of this species on *Oxya hyla*.

Family : Podapolipidae

Genus : *Podapolipus* Rovelli & Grassi, 1888

Generic diagnosis : Adult females with one pair of legs. In larval females, seta *c2* less than half the width of gnathosoma and shorter than prodorsum. Males with anterior aedeagus. Spines absent on tibia. Seta *h1* vestigial or absent.

Podapolipus palappuramensis sp. nov.

(Fig. 1.110-1.114)

Colour: Creamy white

Length: 182 (166–190)

Width: 125 (118–134)

Description

Larval female:

Dorsum (Fig. 1.110 a): Dorsal plate widest at the level of seta *c2*. All dorsal setae smooth and tapered. Prodorsal plate, PrS 102(100–105) covering more than half of the body, bearing three pairs of setae; *v1* 6(6–9), *v2* 9(8–11), *sc2* 62(62–67). Tergite C with two pairs of setae; *c1* 7(7–9), *c2* 8(8–9). Tergite D triangular with one pair of seta, *d* 11(10–13). Tergite EF triangular, with a single pair of seta, *f* 11(9–11). Tergite H not well developed, with one pair of seta; *h2* 175(168–180).

Venter (Fig. 1.110 b): Apodeme I (ap1) fused to presternal apodeme (appr), apodeme II doesnot touch appr. The presternal apodeme extends towards well sclerotised sejugal apodeme (apsej). Apodeme III well developed and fused at the middle. Coxal fields I and II with a single pair of seta each, *1a* 9(8–11) and *2a* 8(7–9). Coxal field III with two pairs of setae, *3a* 8(7–9) and *3b* 8(8–9).

Gnathosoma: Length 63(58–65), width 61(54–63); with one pair of dorsal cheliceral seta *ch3* 6 (33–38), and with one pair of ventral subcapitular setae *su* 14 (12–16), both smooth and pointed. Cheliceral stylets pointed.

Legs (Fig. 1.111): Leg I stouter than the legs II and III. All legs with well developed ambulacra. All leg setae smooth. Chaetotaxy of: Leg I: Fe 1- Ge 0- Ti 4(1)- Ta 5(1), Leg II: Ti 4- Ta 6, Leg III: Ti 4- Ta 4. Seta *d* of tarsus III whip like and longer than the entire leg.

Adult male:

Dorsum (Fig. 1.112 a): Length: 190–207, width: 135–147. Dorsal plate smooth with 8 pairs of setae on the idiosoma. All dorsal setae smooth and tapering. Prodorsal plate PrS 62 (59–65), with three pairs of setae, *v1* 11(10–13), *v2* 10 (9–11), *sc2* 54(53–59). Tergite C with two pairs of setae; *c1* 10(10–12), *c2* 13(12–14), Tergite D and EF overlapping, seta *d* 10(9–12) and *f* 11(11–13). Genital capsule visible on the dorsum extending from the level of seta *d* towards the gnathosoma, length 125(123–129), width 15(13–16).

Venter (Fig. 1.112 b): Apodeme I (apI) fused to presternal apodeme (appr), apodeme II doesnot touch appr. The presternal apodeme extends towards well sclerotised

sejugal apodeme (apsej). Apodeme III well developed and fused at the middle. Coxal fields I and II with a single pair of setae each, *1a* 8(7–10) and *2a* 9(9–11). Coxal field III with two pairs of setae, *3a* 11(10–13) and *3b* 9(8–9).

Gnathosoma: Length 58(55–61), width 56(54–59); with one pair of cheliceral seta *ch* 33(29–35) one pair of subcapitularsetae *su* 8 (7–10), both smooth and pointed. Cheliceral stylets pointed.

Leg (Fig. 1.113): Leg I stouter than the legs II and III. All legs with well developed ambulacra. All leg setae smooth. Chaetotaxy of: Leg I: Fe 1- Ge 0- Ti 6(1)- Ta 7(1), Leg II: Ti 3- Ta 6(1), Leg III: Ti 4- Ta 5. Seta *d* of tarsi II and III longer than the entire tarsus.

Adult female (Fig. 1.113 e): Large, green and spherical. Idiosoma highly distended to form a spherical sac like structure. Egg mass visible. All legs except the first leg (Fig. 1.113 d) vestigial. Tarsus modified into a claw like structure.

Materials examined:

Holotype: Larval ♀, from *O. hyla* collected at Palappuram region (10°46'16.8"N 76°24'31.6"E), Palakkad Dt., Kerala, India on 15.09.2018, Coll. Anjitha K Bhadran.

Paratype: Larval ♀ from *O. hyla* collected at Kavanadu region (10°22'02.4"N 76°19'46.3"E), Thrissur Dt., Kerala, India on 26.12.2018; larval ♀ from *O. hyla* collected at Palappuram region (10°46'16.8"N 76°24'31.6"E), Palakkad Dt. Kerala, India on 29.01.2019; 2 ♂♂ from *O. hyla* collected at Palappuram region (10°46'16.8"N 76°24'31.6"E), Palakkad Dt. Kerala, India on 29.01.2019, Coll. Anjitha K Bhadran.

Type deposition: All type specimens are presently deposited in the Division of Acarology, Dept. of Zoology, University of Calicut. The holotype will be transferred to the Zoological Survey of India, Calicut after publication.

Etymology: The specific epithet '*palappuramensis*' is derived from the name of the type locality, Palappuram.

Remarks: The genus *Podapolipus* includes 30 species. The adult female, larval female and male of the species is very similar to *P. coimbatorensis* described by Ramaraju *et al.*, 1998 from Tamilnadu in the general shape of the body, and in the

dorsal, ventral and leg chaetotaxy. However, several character deviations could be observed in the present specimens when compared to the above species. The adult female of *P. palappuramensis* sp. nov. is pale green in colour (adult female is pale yellow coloured in *P. coimbatorensis*). In larval female of the new species, setae *v1* and *v2* do not reach the base of *sc2* (setae *v1* and *v2* long with their tip reaching the base of *sc2* in *P. coimbatorensis*), seta *sc2* of the new species not longer than the prodorsum (seta *sc2* of *P. coimbatorensis* longer than the prodorsum), setae *d* and *f* of the new species equally long and seta *d* not touching the posterior part of tergite EF (setae *d* and *f* of subequal length and seta *d* touching the posterior part of tergite EF in *P. coimbatorensis*). In the male of the new species, the genital capsule extends from the tergite D to the gnathosoma (genital capsule extends from tergite C to the anterior prodorsum PrS in *P. coimbatorensis*), prodorsum of the new species bears three pairs of setae (prodorsum with four pairs of setae in *P. coimbatorensis*).

Genus : *Locustacarus* Ewing, 1924

Type species : *Locustacarus trachealis* Ewing, 1924

Generic diagnosis : Male and female with three pairs of legs. Pseudostigmatic organs absent in females. Chelicera needle like and curved at the base. Large pedicellate pulvillus and a pair of claws present on the tarsi.

***Locustacarus chinensis* sp.nov.**

(Fig. 1.115 – 1.116)

Colour: Transparent white

Measurements: Length: 172–178

Width: 116–120

Description

Larval female:

Dorsum (Fig. 1.115 a): Dorsal plate widest at the middle narrowing towards the anterior and posterior, ornamented with reticulations. All dorsal idiosomal setae smooth and tapered. Prodorsal plate PrS wider than long, with three pairs of setae; *v1* 8(7–9), *v2* 8(7–10) and *sc2* 68(65–70). Tergite C concave at the posterior, with two

pairs of setae; *c1* 12(10–13) and *c2* 12(12–15). Tergite D semicircular in outline with dimples at the middle, the dimples continuous with the tergite EF which is similar in shape but smaller than tergite D. Tergite D with a single pair of setae *d* 11(10–13) and tergite EF with a single pair of setae *e* 12(11–14). Tergite H reduced dorsally and visible ventrally as a small plate with two pairs of setae, *h1* 15(14–18) and *h2* 230 (215–260).

Venter (Fig. 1.115 b): Apodeme I (apI) and apodeme II (apII) fused to presternal apodeme (appr) which extends posteriorly to fuse with the well developed sejugal apodeme (apsej). Apodeme III interrupted medially. Coxal fields I, II and III with one smooth and tapering setae each, *1a* 8(7–9), *2a* 6(5–9), *3a* 7(5–8).

Gnathosoma: Length 42(39–44), width 41(41–43); with one pair of cheliceral seta, *ch* 26(24–28) dorsally and ventrally with one pair of subcapitular setae *su* 7 (6–8), both setae smooth and pointed. Cheliceral stylets pointed.

Leg (Fig. 1.116): Leg I stouter than legs II and III. All legs with well developed ambulacra. All leg setae smooth. Chaetotaxy of: Leg I: Fe 3- Ge 2- Ti 4(1)- Ta 5, Leg II: Fe 2- Ge 1- Ti 3- Ta 5, Leg III: Fe 1- Ge 1- Ti 4- Ta 4.

Male: Not recovered while sampling.

Materials examined:

Holotype: Larval ♀, from *O. chinensis* collected at Perambra region (10°21'01.7"N 76°19'14.2"E), Thrissur Dt., Kerala, India on 02.06.2018, Coll. Anjitha K Bhadran.

Paratypes: 3 larval ♀♀ from *O. chinensis* collected at Kavanadu region (10°22'02.4"N 76°19'46.3"E), Thrissur Dt., Kerala, India on 20.03.2018, Coll. Anjitha K Bhadran.

Type deposition: All type specimens and specimens of all other species are presently deposited in the Division of Acarology, Dept. of Zoology, University of Calicut. The holotype will be transferred to the Zoological Survey of India, Calicut after publication.

Etymology: The specific epithet '*chinensis*' is derived from the name of host species, *Oxya chinensis* from which the species was collected.

Remarks: The genus *Locustacarus* presently includes four species; *L. trachealis* Ewing, 1924, *L. masoni* Husband, 1974, *L. buchneri* (Stammer, 1951) and *L. aiolopi* Rahmatzaei *et al.* (2021). The present species shows resemblance to *L. buchneri* (Stammer, 1951) in idiosomal chaetotaxy and setal characters. The new species *L. chinensis* sp. nov. differs from *L. buchneri* by the possession of the following characters: Dorsal shield with reticulations (dorsal shield with punctations in *L. buchneri*); dimples arranged in a characteristic conical shape present on the tergites D and EF (no such dimples on the tergite in *L. buchneri*); tergites C and D of the new species non-overlapping (tergite C and D partially overlap in *L. buchneri*); tergite EF semicircular in the new species (tergite EF square shaped in *L. buchneri*); seta *c2* placed at the lateral margin of tergite C in the new species (seta *c2* displaced from the lateral margin of the body in *L. buchneri*); tergite H with two pairs of setae, *h1* and *h2* in the new species (tergite H with one seta *h2* in *L. buchneri*).

Order : Sarcoptiformes Reuter, 1909

Suborder : Oribatida (Duges, 1833)

Cohort : Astigmatina Canestrini, 1891

Superfamily : Histiosomatoidea Berlese, 1897

Family : Histiosomatidae Berlese, 1897

Genus : *Histiostoma* Kramer, 1876

Generic diagnosis: Coxa I with disc *cxI*, coxa III with disc *cxIII*, coxa IV with minute seta *ga* and disc *cxIV*; suctorial plate with two functional suckers, two large central discs and four discs posteriorly and laterally.

***Histiostoma furrowa* sp. nov.**

(Fig. 1.117 – 1.118)

Colour: Creamy white

Measurements: Length: 211(207–225)

Width: 118 (112–121)

Description

Deutonymph :

Dorsum (Fig. 1.117 a): Dorsal shield with five longitudinal furrows extending from anterior hysterosoma towards the posterior side, which could not be visible in the slide mounted specimens, but clearly visible in SEM photographs. Propodosoma triangular with well discernible wavy lines superficially and straight line underneath, parallel to the body margin. Propodosoma with two pairs of setae, *sce* & *sci*, both setae short, simple and slightly shorter than the hysterosomal setae. Inner pair of propodosomal setae originating anteriorly from the outer ones. Dorsosejugal region represented by dorsosejugal suture without ornamentations. Hysterosoma broad and gradually narrowing posteriorly, with nine pairs of short simple setae of almost equal length. Lengths of setae: *sci* 5(4–6), *sce* 3(3–4), *d1* 7(6–8), *d2* 7(6–8), *d3* 7(6–8), *d4* 6(5–6), *d5* 10(9–12), *l1* 7(5–7), *l2* 6(5–7), *l3* 6(5–6), *l4* 6(5–7).

Venter (Fig. 1.117 b): Anterior apodeme of coxa I fused together and continued with the presternal apodeme to form a Y shape, does, but not fused with the sejugal apodeme. Posterior apodeme of coxa I and anterior apodeme of coxa II fused together. Posterior apodeme of coxa II fused to the sternal apodeme. Apodemes III and IV fused to the median apodeme, apodeme IV highly sclerotised. Coxal setae I, III and IV reduced to conoids. Genital region with genital opening and a pair of genital setae *g4*(3–5). Anal region with well developed anal plate (length: 42(41–43), width 50(50–52)). Anal plate with paired suckers; *su*, *b1*, *pd1*, *pd2*, *b2*, *pd3* and unpaired *b3*. Sucker *pd1* largest among all the suckers, well developed placed under the anal opening.

Gnathosoma (Fig. 1.118 e): Infracapitulum cylindrical, palp with well developed palpal solenidion and setae.

Leg (Fig. 1.118 a-d): Legs I- IV with well developed claws. Legs I and II each with a spoon shaped seta, *e*; legs III and IV with seta *e* tapering. Leg chaetotaxy: Co 0-0-0-0, Tr 0-0-1(*sR*)-0, Fe 1(*vF*)-1(*vF*)-0-1(*wF*), Ge 2(*mG*, *cG*)-2(*mG*, *cG*)-0-0, Ti 2 (*hT*, *gT*)- 2 (*hT*, *gT*)-1(*kT*)- 1(*kT*), Ta 6(*la*, *wa*, *ra*, *f*, *d*, *e*)- 7(*ha*, *la*, *wa*, *ra*, *f*, *d*, *e*)- 7(*w*, *r*, *d*, *s*, *p*, *e*, *f*)- 7(*w*, *r*, *d*, *s*, *p*, *e*, *f*). Leg solenidiotaxy consisting of one sigma σ each on genua I and II, one ϕ on all tibia, ω_1 and famulus (ϵ) together with ϕ at tibial apex I and ω_3 on tarsus of leg I.

Adult: Not recovered during sampling.

Materials examined:

Holotype: 3 deutonymphs from *O. longicollis* collected at Moolamkudam region (10°23'19.8"N 76°19'33.4"E), Thrissur Dt., Kerala, India on 16.12.2017, Coll. Anjitha K Bhadran.

Paratypes: 6 deutonymphs collected from the same locality.

Type deposition: All type specimens are presently deposited in the Division of Acarology, Dept. of Zoology, University of Calicut. The holotype will be transferred to the Zoological Survey of India, Calicut after publication.

Etymology: The specific epithet '*furrowa*' is derived based on the possession of the unique feature of the five longitudinal furrows on the dorsal surface of hysterosoma by this species.

Remarks: The present specimens could be easily assigned to the genus *Histiostoma* based on the features of the suctorial plate and coxal discs. The genus *Histiostoma* includes 21 species. The present species is remarkable with five longitudinal furrows on the dorsum. The present species is very close to *H. scindita* Mahunka, 1977 reported from Ecuador in having differentiated *ap3* and sejugal apodemes, and also the dorsosejugal region represented only by a suture. Both species are having eleven pairs of dorsal setae and similar number of suckers in the anal plate. However, the new species possesses several features which could be helpful for differential diagnosis from the above species such as (1) Dorsal setae small and almost similar in length (some of the dorsal setae large in *H. scindita*); remnant of anus situated between suckers *su* (remnant of anus placed underneath *su* in *H. scindita*); seta *e* on legs I and II spoon shaped (seta *e* spoon shaped only on leg I in *H. scindita*); dorsal seta *l4* directed upwards and placed lateral to *d4* (dorsal seta *l4* downwardly directed and placed down the seta *d4* in *H. scindita*).

***Histiostoma herballi* Eraky, 2017**

(Fig. 1.119-1.120)

Colour: Transparent- white

Measurements: Length: 155–162

Width: 60–65

Description

Deutonymph:

Dorsum (Fig. 1.119 a): Propodosoma triangular in outline, a line passing parallel to the anterior propodosomal margin. Propodosomal setae, *sci* and *sce* of the same length, *sce* placed at the posterior corner of propodosoma. Hysterosoma smooth bearing striations along the lateral corner, nine pairs of smooth and pointed setae. Dorso- sejugal region widest at the middle, narrowing laterally and ornamented with striations.

Venter (Fig. 1.119 b): Apodeme I long and fused with *st1* extending to the level of anterior border of apodeme II. Posterior border of apodeme II not fused with each other medially. Apodeme IV fused with *st2*, extending posteriorly as *st3*. The sternum *st2* and *st3* sclerotised, the latter being long, reaching the genital primordium. Coxal regions I, III and IV with well developed coxal discs. Sucker plate with well developed anal discs, *su*, *pd1* and *pd3* of the same size.

Gnathosoma (Fig. 1.120 c): Long and cylindrical infracapitulum, palpalsolenidion long, palpal setae short.

Leg (Fig. 1.120 a, b, d, e): Legs I- IV with well developed tarsal claws. Adhering setae of legs I- IV thin and setiform. Leg chaetotaxy: Leg I: Fe 1- Ge 2- Ti 2 (2)- Ta 7. Leg II: Fe 1- Ge 1- Ti 2 (1)- Ta 5. Leg III: Co 1- Ge 2- Ta 6. Leg IV: Tr 1- Ge 2- Ti+ Ta 8. Solenidiotaxy: $\omega 1$ and ϕ on tibial apex I, ϕ on tibia II.

Adult: Not recovered during sampling.

Materials examined: 2 deutonymphs from *O. obesus* collected at Kanniyampuram (10°46'37.4"N 76°21'01.2"E), Palakkad Dt. on 21.06.2018; 3 deutonymphs from *O. rhinoceros* collected at Muthoor (10°48'11.2"N 76°00'55.7"E), Malappuram Dt. on 26.07.2017; 2 deutonymphs from *O. feae* collected on 21.06.2018 from Thachudaparambu (10°18'34.7"N 76°19'21.1"E), Thrissur Dt., Kerala, India. Coll. Anjitha K Bhadran.

Habitat range: soil under Burmuda grass, *Cynodon dactylon*.

Remarks: The present specimens agree with the species, *H. herballi* described by Eraky *et al.*, 2017 from Egypt in all morphological features. The species is reported for the first time from termites.

***Histiostoma maritimus* (Oudemans, 1914)**

(Fig. 1.121 – 1.122)

Colour: Transparent- white

Measurements: Length: 172–178

Width: 115–120

Description

Deutonymph:

Dorsum (Fig. 1.121 a): Propodosomal margin wavy and posterior margin transverse. Propodosomal setae, *sci* and *sce* of the same size, *sce* originating below the level of *sci*. Dorso-sejugal region narrow, present only as a band. Body widest at the dorso-sejugal region, narrowing below the level of setae, *l3*. Hysterosoma smooth, with ten pairs of short and filiform setae, *d5* being the longest of all dorsal setae.

Venter (Fig. 1.121 b): Apodeme I not reaching to the level of apodeme II, the former being fused to *st1*. Apodeme II long, extending to the medially fused posterior apodeme II. The sternum, *st2* and *st3* sclerotised, *st2* fused to posterior apodeme II and apodeme III fused to *st3*. Coxal fields I, III and IV with coxal discs. Genital primordium with a pair of genital setae arising lateral to it. Anal sucker plate large, disc *pd1* largest among all the discs.

Gnathosoma (Fig. 1.22 d): Infracapitulum long and cylindrical. Palpal solenidion long and thick. Palpal seta short.

Legs (Fig. 1.22 a, b, c, e): Legs I- IV with well developed claws. Legs I and II with spoon shaped adhering setae, *e*. Setae *e* of legs III and IV setiform and thin. Chaetotaxy of : Leg I: Fe 1- Ge 2(1)- Ti 2 (3)- Ta 6(1). Leg II: Ge 2 (1)- Ti 2(2)- Ta 7 (1). Leg III: Ge 1 (1)- Ti+Ta 7. Leg IV: Fe 1- Ti+ Ta 7(1). Solenidiotaxy: σ on genu

I, II and III, φ on tibial apex I, II and on tarsus IV, $\omega 1$ on tibial apex I and II, $\omega 3$ on tibia I and $\omega 2$ on tarsus I.

Adult: Not recovered during sampling.

Materials examined: 3 deutonymphs from *H. vigintioctopunctata* collected at Parappanangadi (11°03'04.4"N 75°51'32.1"E), Malappuram Dt., Kerala, India on 15.06.2018; 4 deutonymphs from *Altica* sp. collected at Thalappara (11°04'42.9"N 75°54'12.6"E), Malappuram Dt., Kerala, India on 11.01.2019, Coll. Anjitha K Bhadran.

Host range: Carabid beetles.

Remarks: The present specimen agrees in morphological features with the species, *H. maritimus* described by Oudemans (1914). This forms the first report of the species being associated with leaf beetles.

***Histiostoma sammari* Eraky, 1999**

(Fig. 1.123 – 1.124)

Colour: Transparent white

Measurements: Length: 125–130

Width: 88–92

Description

Deutonymph:

Dorsum (Fig. 1.123 a): Body ovoid, widest at the dorsosejugal region and narrowing posteriorly. Dorsal surface punctated. Propodosoma, with a dotted line decurrent parallel to the rostral margin, with two pairs of setae, *sce* slightly longer than *sci*. Hysterosoma laterally ornamented and with nine pairs of short and pointed setae.

Venter (Fig. 1.123 b): Apodeme I long and fused to *st1*, extending beyond *la*. Anterior and posterior boundaries of apodeme II fused to each other. Apodemes III not touching each other medially. *st2* sclerotised, not fused to anterior boundary of apodeme III. Apodeme IV fused to *st3*, the latter reaching the genital primordium, terminating with a small apical arch. Coxal regions I, II and IV with well developed

coxal discs. Sucker plate at the anal region placed away from the posterior margin, disc *pd1* the largest among all.

Gnathosoma (Fig. 1.124 e): Infracapitulum cylindrical, palp distinguishable, with palpal seta and solenidion.

Legs (Fig. 1.124 a-d): All legs with normal claws. Seta *e* on leg I spoon shaped and on leg II leaf shaped. Legs III and IV with setiform terminal seta. Chaetotaxy of: Leg I: Fe 1- Ge 2 (1)- Ti 2 (3)- Ta 6 (1). Leg II: Ge 2 (1) - Ti 2 (1) - Ta 7 (1). Leg III: Ti 1 (1) - Ta 7. Leg IV: Ge 1- Ti 1- Ta 8. Solenidiotaxy: σ on genu I and II, ϕ on tibia I, II and III, $\omega 1$ on tibia I and tarsus II, $\omega 3$ on tibia I, $\omega 2$ on tarsus I.

Adult: Not recovered during sampling.

Materials examined: 4 deutonymphs, from *A. foveicollis* collected at Moolamkudam region (10°23'19.8"N 76°19'33.4"E), Thrissur Dt. Kerala, India on 05/11/2018; 2 deutonymphs, from *O. rhinoceros* collected at Moolamkudam region (10°23'19.8"N 76°19'33.4"E), Thrissur Dt. Kerala, India; 2 deutonymphs collected at Nedungottoor (10°45'44.5"N 76°15'42.6"E), Palakkad Dt., Kerala, India on 18/05/2019; 3 deutonymphs from *A. frontalis* collected at Muthoor (10°48'11.2"N 76°00'55.7"E), Malappuram Dt., Kerala, India on 06/07/2018, Coll. Anjitha K Bhadrn.

Habitat range: Termite nest

Remarks: The present specimens agree with the species, *H. sammari* described by Eraky (1999) in all morphological features except that the setae at the mid-dorsal region is visible in the present specimen but is very small in the above species. The species is reported for the first time from leaf beetles.

Genus : *Curculanoetus* Fain, 1974

Diagnosis: Body ellipsoidal. Dorsal surface of hysterosoma reinforced by six longitudinal ridges. The sternum and coxal apodemes II and IV missing. Setae *cx I* and *cx III* filiform. Suctorial plate with two pairs of suction cups, those of the posterior pair being almost vestigial and strongly separated, the four conoids of the plate small, placed very close together and located on a line at the posterior edge of the suctorial plate. Tarsal segments of all legs bear a strong claw and an apical membraneous seta.

***Curculanoetus keralensis* sp. nov.**

(Fig. 1.125 – 1.27)

Colour: Cream

Measurements: Length: 273 (270-279)

Width: 145 (135-146)

Description**Deutonymph:**

Dorsum (Fig. 1.125 a, 1.27): Dorsal shield of hysterosoma reinforced by six longitudinal ridges, wavy in appearance and the lateral ones disappearing caudally. Anteriorly, propodosoma produced into a triangular projection with wavy ornamentation. The lateral sides of propodosoma contain hemispherical projections. Sejugal furrow well visible, (width 8 (7-11)). Three pairs of cupules (*ia*, *im*, *ip*) present, with *ia* located near *h*, *im* between *l*₂ and *l*₃, *ip* anterior to *d*₄. Propodosomal setae (*sci* and *sce*) almost equal in length. Length of propodosoma and hysterosoma: 62(58-63) and 168(164-168), respectively. Length of dorsal setae: *sci* 10(10-11), *sce* (12)11-13, *scx* 6(5-6), *d*₁10(9-12), *d*₂ 10(10-11), *d*₃ 12(9-13), *d*₄ 14(11-15), *d*₅ 13(12-15), *l*₁ 16(13-17), *l*₂ 17(16-18), *l*₃ 17(17-18), *l*₄ 15(14-15), *h* 7(6-8), *sh* 12-14(14).

Venter (Fig. 1.125 b, 1.27): Anterior apodemes of coxa I fused together posteriorly to subcapitular remnant, forming a long sternum, not fused to anterior apodeme of coxa III. Anterior apodeme of coxa II extending towards the anterior coxal apodeme III. Anterior coxal apodeme III fused with posterior apodeme of coxa II and continuing posteriorly as median apodeme; anterior apodeme of coxa IV fused medially with median apodeme which extends posteriorly towards the genital region. Genital region (Figure 2h) anterior to attachment organ, oval with two pairs of genital papillae in genital atrium. Genital setae (*gm*) long 19(17-21) and filiform, positioned antero-lateral to genital opening, setagp8 (6-8) placed postero-laterally to the genital opening. *cxI* 12(10-12) and *cxIII* 4(3-5) filiform. Suctorial plate (Fig. 1.126 e) longer than wide, length: 39(37-39); width: 30(29-32). Posterior pair of suction cups (*vp*) vestigial and separated, while the anterior pair (*va*) more developed and placed lateral

to the anal opening. The four conoids of the suctorial plate small, placed close together and located at posterior edge of suctorial plate.

Gnathosoma (Fig. 1.126 f): Gnathosomal remnant tapering, with length 41(39-44). Remnant of subcapitulum cylindrical, length 13 (10-13), palp 7(6-8), solenidion 24 (22-25), seta 3 (3-4).

Legs (Fig. 1.126 a-d): All tarsi terminated with a strong claw. Seta *e* on legs I-IV falcate. Seta *r* on legs III and IV pectinate. Setae *gT*, *hT*, *mG* and *cG* bifid, while *ra*, *la*, *wa*, *ba*, *p*, *d*, and *f* spine-like. Setation of legs I-IV: Coxae 1(*cxI*)-0-1(*cxIII*)-0; Trochanters 0-0-1(*sR*)-0; Femora 1(*vF*)-0-0-1(*wF*); Genua 2(*mG*, *cG*)-2(*mG*, *cG*)-0-0; Tibiae 2(*hT*, *gT*)-2(*hT*, *gT*)-1(*kT*)-1(*kT*); Tarsi 7(*ba*, *la*, *wa*, *ra*, *f*, *d*, *e*)-7(*ba*, *la*, *wa*, *ra*, *f*, *d*, *e*)-7(*w*, *r*, *d*, *s*, *p*, *e*, *f*)-7(*w*, *r*, *d*, *s*, *p*, *e*, *f*). Leg solenidiotaxy consisting of one σ each on genua I and II, one ϕ on all tibia. ω_1 and famulus (ε) together with ϕ at tibial apex and ω_3 on tarsus of leg I.

Adult: Not collected during sampling.

Holotype: Deutonymph, from the undersurface of elytra of *R. ferrugineus* collected at Moolamkudam region (10°23'19.8"N 76°19'33.4"E), Thrissur Dt., Kerala, India, on 14.01.2018, coll. Anjitha K Bhadrán.

Paratypes: 10 paratypes collected from the same collection locality of the holotype.

Type deposition: All type specimens and specimens of all other species are presently deposited in the Division of Acarology, Dept. of Zoology, University of Calicut. The holotype will be transferred to the Zoological Survey of India, Calicut after publication.

Etymology: The species epithet '*keralensis*' is derived from Kerala, the southernmost State in India which encompasses the type locality.

Remarks: The genus *Curculanoetus* was erected by Fain (1974) under the family Histiostomatidae, based on the deutonymph of the type species collected from the host, *R. phoenicis* from Congo. The present species forms a second addition to the genus. The unique features of the taxon include the presence of six longitudinal ridges on the dorsum, vestigial posterior suction cups and four conoids on the plate which are close together. Based on the leg features and the configuration of suctorial plate, the new species has been assigned to the genus *Curculanoetus*. The new species is

distinct from its congener, *C. rhynchophorus* by the possession of features like : the six longitudinal ridges represented by wavy lines (beaded lines in *C. rhynchophorus*); sejugal furrow widening towards the midline and thinning laterally (evenly wide sejugal furrow in *C. rhynchophorus*); sejugal furrow ornamented with latitudinal lines; palpal supracoxal seta present (absent in *C. rhynchophorus*); sternum, epimeres II and IV clearly demarcated than those of *C. rhynchophorus*; the median apodeme extends towards the genital region (median apodeme stops halfway in *C. rhynchophorus*); anterior pair of suction cups (*va*) present at the apical region of suctorial plate and placed close together laterally to the anal valve (the distance between *va* more prominent in *C. rhynchophorus*). Moreover, the body length is less than half of the width in the new species whereas in *C. rhynchophorus*, body length is more than one and half times the width.

Superfamily : Canestriniodea Berlese, 1884

Family : Canestriniidae Berlese, 1884

Genus : *Canestriniella* Berlese, 1910

Generic diagnosis : All dorsal setae except *sce* and caudal setae short in females. Tarsi III-IV with one usual long seta. In males, opisthosoma distinctly narrower than hysterosoma, epimere I fused. Ventral side of male bearstwo large anal suckers. Claw like spur on tarsi III-IV.

***Canestriniella batocera* sp. nov.**

(Fig. 1.128 – 1.131)

Colour: Cream

Measurements: Length: 505(500– 515)

Width: 375(370–377)

Description

Adult female:

Dorsum (Fig. 1.128 a, 1.131): Dorsum ornamented with reticulations and widest at the middle of idiosoma. Idiosomabears 12 pairs of smooth and tapering setae. Dorsal

seta *se* 153(150–190) longest among all other setae. Prodorsum with two pairs of setae; *scx* 55(54–62) and *vi* 64(62–68). No particular demarcation between the prodorsum and hysteronotum. Hysteronotal setae 9 pairs; *c1* 24 (23–26), *c2* 24 (22–29), *d1* 26(25–31), *d2* 25(24–27), *h1* 29(28–31), *h2* 21(20–22), *f2* 21(19–22). Seta *c3* 19(18–21), arising lateral to the hysterosomal margin.

Venter (Fig. 1.128 b, 1.131): Apodeme I well developed and fused with the presternal apodeme to form a ‘V’ shape. Posterior and anterior boundaries of apodeme II well developed and sclerotised but not fused with each other. Sejugal apodeme vestigial. Coxal fields I with a single seta, *1a* 85(83–89), coxal field III with two setae, *3a* 97(95–98) and *3b* 22(21–24), coxal field IV with a single seta, *4a* 63(60–67). Genital apparatus placed at the level of coxae III and IV, with relatively large genital suckers, placed lateral to the genital opening. Genital setae two pairs; *g1* 16(14–17) and *g2* 17(15–17). Anal opening positioned below the genital opening, with three pairs of adanal setae; *ad1* 14(12–16), *ad2* 13(11–14) and *ad3* 34(32–36). Two pairs of setae placed posterior to anal opening; *ps2* 195(190–210) and *h3* 237 (226–243).

Gnathosoma: Length: 105(102–107), width: 98(97–99). Two pairs of gnathosomal setae, one pair dorsal and one pair ventral.

Adult male:

Dorsum (Fig. 1.129 a): Length: 370 (368–372), width: 68 (65–69). Dorsum with reticulations, widest at the level of *c2* and assuming a vase shape at the posterior. Prodorsum with two pairs of setae; *scx* 55(54–58), *vi* 68(65–72). Hysterosomal setae eight pairs; *si1* 17(15–18), *se* 154(150–155), *c1* 17(15–19), *c2* 16(14–17), *cp* 15(14–17), *d1* 14(12–15), *d2* 14(13–14), *e1* 17(15–18).

Venter (Fig. 1.129 b): Apodeme I well developed and fused with the presternal apodeme to form a ‘V’ shape. Posterior and anterior boundaries of apodeme II well developed and sclerotised but not fused with each other. Sejugal apodeme vestigial. Coxal field I with a single seta, *1a* 44 (42–47), coxal field III with two setae, *3a* 17 (15–18) and *3b* 65 (64–68). Genital apparatus bottle neck shaped, with two pairs of suckers and two pairs of setae, *g1* 11 (10–13) and *g2* 12 (10–13) placed lateral to the opening. Anal opening small, with well developed anal suckers. Adanal seta two pairs, *ad1* 13 (11–14), *ad2* 12 (11–13). A single pair of setae placed posterior to the anal

opening, *ps1* 21(19–22). Insertions of setae *ps2*, *ps3* clearly visible ventrally. Four pairs of setae placed posterior end; *ps2* 67(65–68), *ps3* 13(12–15), *h1* 12 (11–14) and *h2* 26(23–27).

Gnathosoma: Length: 80(75–87), width: 68(65–69). Two pairs of gnathosomal setae one pair dorsal and one pair ventral.

Legs (Fig. 1.130): Legs I-IV with well developed ambulacra. Chaetotaxy of Leg I: Tr 1 (*vTr*)- Fe 0- Ge 2 (*cG*, *mG*) (1)- Ti 0 (1)-Ta 7 (*la*, *wa*, *ra*, *q*, *s*, *d*, *e*) (1); Leg II: Fe 1 (*vF*)- Ge 2 (*cG*, *mG*) (1)- Ti 0 (1)- Ta 5 (*wa*, *la*, *ra*, *p*, *s*)(1); Leg III: Tr 1(*vTr*)- Ge 1 (*mG*)- Ti 0 (1)- Ta 3 (*s*, *d*, *e*); Leg IV: Ti 0 (1)- Ta 4 (*wa*, *d*, *e*, *q*). Solenidiotaxy: one σ each on genua I and II, one ϕ each on tibia I-IV, one ω each on tarsi I and II.

Materials examined: Holotype: Adult ♀ from *B. rufomaculata* collected at Moolamkudam region (10°23'19.8"N 76°19'33.4"E), Thrissur Dt., Kerala, India on 07.06.2018,. Coll. Anjitha K Bhadran.

Paratypes: 5 ♀♀ and 3 ♂♂ from *B. rufomaculata* collected at the same collection locality of the holotype, Coll. Anjitha K Bhadran.

Type deposition: All type specimens are presently deposited in the Division of Acarology, Dept. of Zoology, University of Calicut. The holotype will be transferred to the Zoological Survey of India, Calicut after publication.

Etymology: The specific epithet '*batocera*' is derived from the host insect, *B. rufomaculata* from which the species was collected.

Remarks: The present species possesses all the generic characters and hence included in this genus. The species is very similar to *Canestriniella elae* described by Haitlinger (1989) obtained from the host, *Batocera ferruginea* from Sumatra. The idiosoma of both the male and female specimens resembles that of *C. elae*. The body ornamentation as well as nature of bodysetae of both species also appear similar. However, the present species differs from *C. elae* in the following characters: (1) Dorsum with 11 and 10 pairs of setae in the female and male specimens respectively (Dorsum with 10 pairs and 9-11 pairs of dorsal setae in the female and male of *C. elae*); (2) Dorsal ornamentation prominent with all dorsal area equally ornamented in *C. batocera* sp. nov. (Dorsal ornamentation poorly visible with the middle part of dorsum lacking ornamentation in *C. elae*); (3) Genital opening with

two pairs of genital valves present on genital suckers in *C. batocera* sp. nov. (Genital suckers not visible and genital valves placed adjacent to the genital opening in *C. elae*); (4) Ventral part of lobe with five pairs of setae in the males of *C. batocera* sp. nov. (Ventral part of lobe with eight pairs of setae in *C. elae*). The genus is found associated with various species of *Batocera*. This is the first report of the genus associated with *B. rufomaculata*.

Genus : *Athogavia* Haitlinger, 1989

Generic Diagnosis : Idiosoma long with partially ornamented dorsal integument. No suture separating propodosoma and hysterosoma. All body setae smooth, except for some rare idiosomal serrate setae. Epimere I Y shaped. Tarsus IV with two thick setae.

Athogavia oryctae sp. nov.

(Fig. 1.132 – 1.135)

Colour: Cream

Measurements: Length: 452(450–486)

Width: 310(307–315).

Description

Adult female:

Dorsum (Fig. 1.132 a, 1.135): Dorsum faintly reticulated, widest at the level of seta *c3*. Idiosoma with 12 pairs of setae, setae *se*, *cp*, *e2* and *f2* longer than all other dorsal setae, *e2* being the longest. Length of setae: *vi* 45(43–46), *si25*(24–26), *se* 268(266–271), *c1* 53(50–55), *c2* 39(37–40), *cp* 352(347–355), *d1* 52(50–54), *d2* 38(35–39), *e1* 30(29–32), *e2* 425(420–428), *h1* 32(31–33), *f2* 325(320–327), *ps1* 41(40–43), *h3* 58(56–59).

Venter (Fig. 1.132 b, 1.135): Apodemes I–IV well developed and sclerotised, apodeme I some what Y shaped. Coxal field I with a single pair of seta, *1a*, coxal field III with two pairs of setae; *3a* and *3b*, coxal field IV with a single pair of seta, *4a*. Genital apparatus with an inverted Y shaped, genital seta *g* present above the genital apparatus. Anal opening oval with four pairs of setae; placed anterior to the anal opening, *ad1*, *ad2* placed lateral to the anal opening. Insertion of setae *ps2*, *ps3*

and *c3* clearly visible ventrally, seta *c3* present above leg III. . Lengths of setae; *1a* 21(20–23), *3a* 18(16–19), *3b* 35(34–37), *4a* 17(15–19), *g* 15(15–16), *ps2* 14(12–15), *ps3* 22(20–23), *ad1* 8(7–9), *ad2* 20(18–21), *c3* 56(54–57).

Adult male: Length: 374(365–382), width: 192(186–195).

Dorsum (Fig. 1.133 a): Dorsal chaetotaxy similar to that of female except for the lengths of setae. Lengths of setae: *vi* 27(25–28), *si* 16(14–17), *se* 247(245–252), *c1* 83(80–85), *c2* 52(51–54), *d1* 85(83–87), *d2* 66(62–67), *cp* 245(240–248), *e1* 70(68–72), *e2* 240(236–242), *h1* 41(40–43), *f2* 270(265–272).

Venter (Fig. 1.133 b): Apodemes I–IV sclerotised and not fused with each other. Coxal field I with a single pair of seta, *1a*; coxal field III with two pairs of setae, *3a* and *3b* and coxal field IV with a single pair of seta, *4a*. Genital field granulated with circular genital apparatus. Anal region with granulations, arranged in a circular fashion. Adanal setae two pairs; *ad1* and *ad2*. Lengths of setae: *1a* 25(23–26), *3a* 17(15–19), *3b* 19(17–20), *4a* 19(18–20), *g* 14(12–15), *ad1* 19(17–20), *ad2* 22(21–24), *ps2* 16(14–17), *ps3* 18(15–19), *h3* 205(202–210).

Gnathosoma: Length: 98(96–99), width: 59(58–60)

Legs (Fig. 1.134): Leg IV longest of all the legs. Legs I–IV with well developed ambulacra. Leg chaetotaxy: Leg I: Fe 1- Ge 2(1)- Ti 0(1)- Ta 5(2), leg II: Fe 1- Ge 2(1)- Ti 0(1)- Ta 4(1), leg III: Tr 1- Fe 0- Ge 0(1)- Ti 0(1)- Ta 2(1), leg IV: Tr 1- Fe 0- Ge 0- Ti 0(1)- Ta 5(1). Solenidiotaxy: σ_1 on leg I–III, ϕ on tibia I–IV, ω_1 on tarsus I–IV, ω_3 on tarsus I.

Materials examined: Holotype: Adult ♀ from *O. rhinoceros* collected at Moolamkudam region (latitude 10.3838° and longitude 76.3256°), Thrissur Dt., Kerala, India on 05/10/2018, Coll. Anjitha K Bhadrn.

Paratypes: 5 ♀♀ and 4 ♂♂ from *O. rhinoceros* collected from the same locality along with the holotype, Coll. Anjitha K Bhadrn.

Type deposition: All type specimens are presently deposited in the Division of Acarology, Dept. of Zoology, University of Calicut. The holotype will be transferred to the Zoological Survey of India, Calicut after publication.

Etymology: The specific epithet '*oryctae*' is derived from the name of host insect *O. rhinoceros* from which the species was collected.

Remarks: The present species possesses all diagnostic features of the genus *Athogavia* and hence fixed so. The species is very similar to *A. tanzanica* described by Haitlinger (1989) in body setae, leg chaetotaxy as well the type of setae. The species *A. tanzanica* was obtained from *O. monoceros* from Tanzania. However, the present species differs from *A. tanzanica* in characters like: Dorsal integument with even cell like ornamentations (Dorsal integument with uneven cell like ornamentation, posterior idiosoma with distinctly shaped cellulae in *A. tanzanica*); Posterior idiosoma with two pairs of long setae (*e2* and *f2*) (Posterior idiosoma with one pair of long setae (*f2*) in *A. tanzanica*); Genital apparatus inverted 'Y' shaped in the female and circular in the male (Genital apparatus with two pairs of valve like structures in both male and female in *A. tanzanica*); and Two pairs of ventral posterior setae (*ps1* and *h3*) of equal length. (One pair of ventral posterior setae (*h3*) longer than *ps1* in *A. tanzanica*). The genus is a constant associate of scarabaeid beetles and members of the genus *Oryctes*. The genus is reported for the first time from *O. rhinoceros*.

Superfamily : Hemisarcoptoidea Oudemans, 1908

Family : Hemisarcoptidae Lignieres, 1893

Genus : Congovidia Fain & Elsen, 1971

Generic description: Propodosoma with well developed eyes. Palposoma either weakly developed or absent. Epimere III free. Tarsi I-IV with 6-6-3-4 setae. Tibia I and II with one seta each. Genua I and II with two setae each.

***Congovidia glossinae* Fain & Elsen, 1971**

(Fig. 1.136 – 1.37)

Colour: Tan

Measurements: Length: 153–158

Width: 90–95

Description

Deutonymph:

Dorsum (Fig. 1.136 a): Propodosoma subtriangular with three pairs of setae, *scx*, *sci* and *sce*. Rostrum with a pair of well developed eyes and granulations around the eyes. All dorsal setae short and needle like. Dorsosejugal region represented by a dorsosejugal suture, without ornamentations. Hysterosoma widest at the level of seta *l₁* and narrowing posteriorly. Hysterosoma with granulated ornamentations throughout, with eight pairs of setae and two pairs of cupules, *ia* placed below the seta *l₁*, *gla* seen below, but lateral to the seta *l₂*.

Venter (Fig. 1.136 b): Anterior apodeme of coxa I fused to the presternal apodeme. Posterior apodeme of coxa I and anterior apodeme of coxa II fused to each other, but not reaching the presternal apodeme. Posterior apodeme of coxa II free, sejugal apodeme vestigial. Apodemes III and IV sclerotised and fused to the well developed median apodeme. Coxal fields I and III with suckers *1a* and *3a*. Coxal field IV with two setae, *4a* and *4b*. Remnants of genital opening oval shaped with a single pair of genital setae, *g* and two pairs of suckers; seta *ad3* placed below the genital opening. Anal region with well developed anal plate containing three pairs of suckers.

Gnathosoma: Chelicera and palps vestigial. Infracapitulum poorly developed with a pair of short and filiform setae.

Legs (Fig. 1.137): Legs III and IV reduced, anterior legs I and II longer. Tarsi I and II bear a single leaf like seta each. All leg segments free, tibia and tarsus of leg IV fused. Leg I with tibial solenidia ϕ longer than the tarsus. Seta *e* on tarsus IV very long and whip like. Leg chaetotaxy: Leg I: Fe 1- Ge 2 (1)- Ti 1 (1)- Ta 6 (2). Leg II: Fe 1- Ge 2 (1)- Ti 1 (1)- Ta 6 (1). Leg III: Ti 1 (1)- Ta 3. Leg IV: Fe 1- Ti+ Ta 4. Solenidiotaxy: ϕ on tibia I, II and III, $\omega 3$ and $\omega 1$ on tarsus I, $\omega 1$ on tarsus II.

Adult: Not recovered during sampling.

Materials examined: 2 deutonymphs, from *H. vigintioctopunctata* collected at Villunniyal (11°07'39.7"N 75°53'14.0"E), Malappuram Dt., Kerala, India on 26.10.2018, Coll. Anjitha K Bhadrar.

Host range: Bees

Remarks: The present species agrees in all respects with the species *C. Glossinae* erected by Fain and Elsen (1971). The species is reported for the first time from *H. vigintioctopunctata*.

Family : Winterschmidtidae Oudemans, 1923

Genus : *Procalvolia* Fain, 1971

Generic diagnosis: Eyes present on the propodosoma. Posterior tarsi without chitinous extension. Tarsi I-IV with 6-6-8-6 setae, all setae simple and non foliate. Palposoma with two setae. Tibia and genua of legs I and II with two setae each.

***Procalvolia* sp.**

(Fig. 1.138 – 1.139)

Colour: Creamy white

Measurements: Length: 263–268

Width: 158–165

Description

Deutonymph:

Dorsum (Fig. 1.138 a): Body ovoid, widest at the dorsosejugal region, rostrum wide. Dorsal surface reticulated. Dorsosejugal region widest at the medial line and disappearing towards the lateral margins. Propodosoma reticulated and bears a pair of eyespots at the anterior apex of the rostrum. Two pairs of setae, *sce* and *sci* present on the propodosoma, the former slightly longer than the latter. Hysterosoma with eight pairs of short and pointed setae.

Venter (Fig. 1.138 b): Anterior apodeme I long, fused to *stl* and not reaching the posterior border of apodeme II. The posterior border of apodeme I and anterior boundary of apodeme II meet each other. Posterior apodeme II free and not fused to sejugal apodeme. Anterior and posterior borders of apodeme III fused with each other, median apodeme well developed between coxae IV only. Coxal region with three pairs of setae, *2b*, *3a* and *4a*. Sucker plate at the anal region well developed.

Gnathosoma: Infracapitulum cylindrical, palp distinguishable, with palpal seta and vestigial solenidion.

Legs (Fig. 1.139): All legs with well developed ambulacra. Seta *e* on leg IV longer than the entire leg. Leg chaetotaxy: Leg I: Tr 1- Fe 1- Ge 2 (1)- Ti 2 (1)- Ta 6 (3); Leg II: Tr 1- Fe 1- Ge 2 (1) - Ti 2 (1) - Ta 6 (1); Leg III: Tr 1- Ge 1-Ti 1 (1) - Ta 8; Leg IV: Fe 1- Ti 1- Ta 6. Solenidiotaxy: σ on genua I and II, ϕ on tibia I, II and III, ωI on tibia I, $\omega 3$ on tarsi I and II, $\omega 2$ on tarsus I.

Adult: Not recovered during sampling.

Materials examined: 5 deutonymphs from *A. foveicollis* collected at Moolamkudam (10°23'19.8"N 76°19'33.4"E), Thrissur Dt., Kerala, India on 05.11.2018 ; 3 deutonymphs from *H. unicolor* collected at Moolamkudam (10°23'19.8"N 76°19'33.4"E), Thrissur Dt., Kerala, India on 02.01.2018,. Coll. Anjitha K Bhadrar.

Host range: Carpenter bees, honeybees

Remarks: The specimens collected during the study agree with the members of the genus *Procalvolia* in all characters and hence assigned to this taxon. This forms the first report of the genus *Procalvolia* from Indian subcontinent on *A. foveicollis* and *H. unicolor*.

Superfamily : Acaroidea Latreille, 1802

Family : Acaridae Latreille, 1802

Genus : *Acarus* Linnaeus, 1758

Generic diagnosis: Deutonymph with gnathosoma approximately rounded, bearing a pair of setae. Propodosoma subtriangular with two pairs of setae. Suctorial plate large, extending to the posterior margin of the body. Legs short and stout with the third and fourth pairs directed backwards.

Acarus solimani Eraky, 1999

(Fig. 1.140 – 1.141)

Colour: Creamy white

Measurements: Length: 80–95

Width: 55–62

Description

Deutonymph:

Dorsum (Fig. 1.140 a): Body circular in outline. Propodosoma ornamented with a triangular wavy line passing below the semicircular anterior rostrum. Setae, *ve*, *sce* and *sce* present on the propodosoma, *sci* below *sce*. Hysterosoma smooth, with nine pairs of short and pointed setae.

Venter (Fig. 1.140 b): Apodeme I (*ap1*) long and extending to *st1*. Apodeme II (*ap2*) extending to the level of *st1*. Apodeme III (*ap3*) and apodeme IV (*ap4*) not fused. Coxal regions of legs I, III and IV with coxal discs. Genital seta, *g* present lateral to the primordial genital region. Sucker plate at the anal region circular, placed far from the posterior margin of the body, with discs, *ps1*, *ps2*, *ps3*, *ad1-2* and *ad3*.

Gnathosoma: Gnathosoma with distinct palpi and infracapitulum, palpal seta and solenidion present.

Legs (Fig. 1.141): Leg I long with spoon shaped adhering seta, *e*. Seta *e* on leg II setaceous. Seta *d* on leg IV leaf shaped. Leg chaetotaxy: Coxae: 0-0-0-0, Trochanters: 0-0-0-0, Femora: 0-1-0-0, Genua: 1-0-0-1, Tibia: 2-0-1-0, Tarsi: 4-4-4-4. Solenidiotaxy: one σ on genu I, one ϕ each on tibia I and II, one ω each on tarsi I and II.

Adult: Not recovered during sampling.

Materials examined: 5 deutonymphs, from *N. gardneri* collected at Panamanna (10°48'34.9"N 76°21'00.2"E), Palakkad Dt., Kerala, India on 18.06.2019, Coll. Anjitha K Bhadrán.

Habitat/Host range: Stored products, termites.

Remarks: The specimens examined agree in morphology with that of *A. solimani* described by Eraky, 1999 from Aswan. The species has been reported from termites. This forms the first report of its occurrence with termites from India.

Genus : *Rhizoglyphus* Claparede, 1869

Generic diagnosis: Body of deutonymph oval in outline. Propodosoma with four pairs of setae. Dorso-sejugal furrow narrow. Hysterosoma smooth or punctated, bearing smooth and simple setae. Coxal fields I and III with coxal discs, not developed to setae. Suctorial plate of the anus large, placed close to the posterior margin of the body.

***Rhizoglyphus vicantus* Manson, 1977**

(Fig. 1.142 – 1.43)

Colour: Tan

Measurements: Length: 350–375

Width: 265–280

Description**Deutonymph:**

Dorsum (Fig. 1.142 a): Propodosoma triangular with a tapering rostrum and with four pairs of setiform setae. Dorso-sejugal region represented by a band. Hysterosoma ornamented with punctations, with a characteristic semi-circular dark region at the mediolateral hysterosomal region. Ten pairs of smooth, and pointed setae present on the hysterosoma.

Venter (Fig. 1.142 b): Apodeme I and *st1* joined to form a Y shape under the gnathosoma. Anterior apodeme II fused with posterior apodeme I, extending beyond *st1*. Posterior apodeme II fused to medially fused anterior apodeme III. Sternum *st2* and *st3* sclerotised, latter extending to the genital primordium. Coxal fields I, III and IV with coxal discs. Genital setae present lateral to the genital primordium. Lateral segment of venter ornamented with striations, and with two pairs of setae, *f2* & *h3*. Sucker plate at the anal region well developed, with seven pairs of discs.

Gnathosoma (Fig. 1.143 d): Infracapitulum long, widening towards posterior region and with one pair of setae. Palp with a pair of long and thick solenidia and setae.

Legs (Fig. 1.143): All legs terminating in a sharp claw. Leg chaetotaxy: Leg I: Fe 1- Ge 2 (1)- Ti 2 (1)- Ta 8 (3); Leg II: Fe 1- Ge 2 (1)- Ti 2 (1)- Ta 8 (1); Leg III: Ge 1- Ti 1 (1)- Ta 8; Leg IV: Fe 1- Ti 1 (1) –Ta 8. Solenidiotaxy: σ on genu I and II, φ on tibia I- IV, $\omega 1$ each on tarsi I and II, $\omega 3$ and $\omega 2$ on tarsus I, famulus ε on tarsus I.

Adult: Not recovered during sampling.

Materials examined: 3 deutonymphs from *O. obesus* collected at Moolamkudam (10°23'19.8"N 76°19'33.4"E), Thrissur Dt., Kerala, India on 26.07.2018; 2 deutonymphs from *O. feae* collected at Thrikkangodu (10°45'52.4"N 76°21'07.5"E), Palakkad Dt., Kerala, India on 26.07.2018, Coll. Anjitha K Bhadran.

Habitat range: Leaf litter

Remarks: The specimens are very similar to *R. vicantus* described by Manson, 1977 from Colombia in all respects and hence fixed so. This forms the first report of its association with termites.

Genus : *Acotyledon* Oudemans, 1903

Generic diagnosis: Body shape ranges from oval to spherical. Propodosoma with three pairs of setae. Dorso-sejugal furrow well developed. Hysterosomal shield doesnot cover the dorsal hysterosoma entirely. Some dorsal setae placed off the hysterosomal shield. Apodeme II not reaching apodeme IV.

***Acotyledon tariqi* Ashfaq, Sher, Chaudhri and Aslam, 1987**

(Fig. 1.144 – 1.145)

Colour: Dark brown

Measurements: Length: 230–240

Width: 185–196

Description

Deutonymph:

Dorsum (Fig. 1.144 a): Body oval in outline with the propodosomal and hysterosomal shields. Anterior part of the propodosoma nearly triangular, bearing five pairs of setae,

vi, *ve*, *sci*, *scs* and *sce*. Dorsum without any visible pores. Setae *d1*, *d2*, *d3*, *d4*, *sae*, *sai*, *he*, *hi*, *la*, *lp1* and *lp2* present on the hysterosomal shield. Dorsosejugal region wide and ornamented with punctations. Hysterosomal shield with linearly arranged granulations, at the lateral borders.

Venter (Fig. 1.144 b): Apodeme I long and V shaped, continuing with the sternum *st1*, the latter free and with blunt end. Anterior apodeme II and *st1* end at the same level, not reaching the fused posterior apodeme II. The sternum *st2* fused to the posterior apodeme II. Coxal discs, *1a*, *3a* and *4a* present. Sucker plate of the anal region wider than long, with the genital setae, *g* placed anterior to it. Median disc, *pd1* larger among all the discs.

Gnathosoma (Fig. 1.145 e): Infracapitulum of gnathosoma oblong and cylindrical with distinct palpi, one pair of palpal setae present. Palpal solenidia long and thick.

Legs (Fig. 1.145 a-d): All legs long with well developed claws. Leaf shaped setae present on all tarsi. Leg chaetotaxy: Coxa: 0-0-0-0, Trochanter: 0-0-1-0, Femur: 0-0-1-1, Genu: 2-1-1-0, Tibia: 2-2-1-1, Tarsus: 6-7-8-8. Solenidiotaxy: One σ present on genua of legs I and II; one ϕ present on tibia of leg IV; one ω and a long famulus present on tarsi of legs I and II.

Adult: Not recovered during sampling.

Materials examined: 5 deutonymphs five from *N. gardneri* collected on 15.07.2017, C.U campus (11°08'01.9"N 75°53'26.3"E), Malappuram Dt.; 7 deutonymphs from *O. rhinoceros* eggs collected on 23.08.2017 from Moolamkudam region (10°23'19.8"N 76°19'33.4"E), Thrissur Dt., Kerala, India, Coll. Anjitha K Bhadran.

Habitat range: Chick pea.

Remarks: The specimen examined agree with the features of *A. tariqi* described by Ashfaq *et al.*, 1987 from Pakistan. The species is reported for the first time in association with termites and *O. rhinoceros*.

Genus : *Sancassania* Oudemans, 1916

Generic diagnosis: Vertical setae present and short. Tarsal seta *e* on legs I and II saucer shaped. Genua III-IV not distinctly longer than tibiae III-IV. No dorsal solenidion on genu III. No striated membrane posterior to the attachment organ.

***Sancassania boharti* Cross, 1968**

(Fig. 1.146 – 1.147)

Colour: Tan

Measurements: Length: 253–265

Width: 180–185

Description**Deutonymph:**

Dorsum (Fig. 1.146 a): Propodosoma with a tapering rostrum, ornamented with two lines decurrent parallel to the anterior propodosomal margin. Propodosoma ornamented with punctations adjacent to the dorso-sejugal region, five pairs of smooth and pointed setae. Hysterosoma ornamented with punctations, visibly underneath the dorso-sejugal region, with 11 pairs of setae. Dorso-sejugal region with striated ornamentations. Lateral parts of the venter ornamented with striations. Three pairs of setae and a disc present on the lateral segment.

Venter (Fig. 1.146 b): Apodeme I fused to the *st1*, extending beyond *1a*. Apodeme II free, not reaching the medially fused apodeme III. The sternum *st2* and *st3* sclerotised, the latter extending to the genital primordium. Coxalfields I, III and IV with coxal discs. Sucker plate at the anal region well developed, placed away from the posterior margin of the body.

Gnathosoma (Fig. 1.147 c): Infracapitulum and palp differentiated. Two short setae and a long solenidion present on the palp.

Legs (Fig. 1.147 a, b, d, e): Tarsi of legs I- IV terminating in sharp well developed claws. Solenidion ϕ of tibia I long, reaching beyond the tarsal tip. Adhering setae *e* of legs I and II spoon shaped, leg III setiform and leg IV leaf shaped. Leg chaetotaxy: Leg I: Fe 1- Ge 2 (1)- Ti 2 (1)- Ta 9 (4). Leg II: Fe 1- Ge 2 (1)- Ti 2 (1)- Ta 8 (1). Leg III: Fe 1- Ti 1 (1)- Ta 8. Leg IV: Ge 1- Ti 1 (1)- Ta 7. Solenidiotaxy: σ on genu I and II, ϕ on tibia I-IV, $\omega 1$ on tarsus I and II, $\omega 2$ on tarsus I, a short famulus ε on tarsus I.

Adult: Not recovered during sampling.

Materials examined: 3 deutonymphs, from *O. rhinoceros* collected at Moolamkudam (10°23'19.8"N 76°19'33.4"E), Thrissur Dt., Kerala, India on 23.03.2018; 2 deutonymphs from *O. obesus* collected at Kuttikattoor (11°15'58.0"N 75°52'23.5"E), Kozhikode Dt., Kerala, India on 12.11.2018, . Coll. Anjitha K Bhadran.

Host range: *Nomia melanderi*, diplopods, millipedes

Remarks: The specimens examined show great morphological similarity to *S. boharti* described by Cross, 1968 from North America. The species is reported for the first time in association with *O. rhinoceros*.

Genus : *Schweibea* Oudemans, 1916

Generic diagnosis: Body ovoid in outline with a smooth integument. Gnathosomal infracapitulum long and indistinctly subdivided, with a pair of well developed solenidia, often longer than the gnathosoma. A pair of pigmented sclerites present at the edge of the rostrum. Dorso-sejugal furrow with striations. Some of the dorsal setae placed off the hysterosomal shield.

Schweibea sp.

(Fig. 1.148 – 1.149)

Colour: Tan

Measurements: Length: 195–201

Width: 155–164

Description

Deutonymph:

Dorsum (Fig. 1.148 a): Propodosoma with a wavy anterior margin. Three pairs of setae present on the propodosoma, *vi* shorter than *sce* and *sci*, the latter two setal pairs equally long. All dorsal setae smooth and pointed. Dorso- sejugal region wide with striated ornamentation. The lateral portions of the dorso-sejugal region bear thick punctations, arranged in a circular fashion. Hysterosoma smooth, with 11 pairs of short, smooth setae, of which five pairs arranged on the lateral shields. Lateral shields carry striated ornamentations, visible clearly in ventral view.

Venter (Fig. 1.148 b): Apodeme I (*ap1*) fused to *st1*, extending beyond *la*. Apodemes II fused with each other. Apodeme III fused to *st2*. Apodeme IV fused to *st3*, extending to the genital primordium. Coxal fields I, III and IV with coxal discs. Sucker plate at the anal region longer than wide, placed away from the posterior margin of the body, and bears 5 pairs of well developed discs for adhesion.

Gnathosoma: Infracapitulum rectangular with distinguishable palp. Palpal solenidia long while palpal setae short.

Legs (Fig. 1.149): Legs III and IV shorter than legs I and II. A spoon shaped adhering seta, *e* present on tarsus I. Setae *e* on legs II, III and IV setiform, that of leg III longer than the tarsus. Leg chaetotaxy: Leg I: Fe 1- Ge 2- Ti 2- Ta 6 (3); Leg II: Fe 1- Ge 2 (1)- Ti 2- Ta 8 (1); Leg III: Fe 1- Ti 2- Ta 6; Leg IV: Ti 2- Ta 9. Solenidiotaxy: σ on tarsus II, $\omega 1$ each on tarsi I and II, $\omega 3$ and ϕ on tarsus I.

Adult: Not recovered during sampling.

Materials examined: 3 deutonymphs from *O. feae*, collected at Kanniyampuram (10°46'37.4"N 76°21'01.2"E), Palakkad Dt., Kerala, India on 18.04.2018, Coll. Anjitha K Bhadrn.

Remarks: The present species looks very similar to *Schweibea nova* (Oudemans, 1906) in the chaetotaxy of the dorsum and legs. However certain character deviations could be noted in the present specimens as follows: The body is almost circular in outline in *Schweibea* sp. (body is oval in outline in *S. nova*); posterior apodeme II is free in *Schweibea* sp. (posterior apodeme II fused with each other in *S. nova*); circular eye shaped granulations at the junction of dorsosejugal region and idiosoma in *Schweibea* sp. (circular eye shaped granulations present on the idiosoma in *S. nova*.)

Genus : *Caloglyphus* Berlese, 1923

Generic diagnosis: Propodosoma subtriangular with two pairs of setae. Dorso-sejugal furrow well developed and striated. Lateral parts of hysterosoma striated with some of the hysterosomal setae. Coxal fields I and III with coxal discs.

Caloglyphus manuri Eraky and Osman, 2008

(Fig. 1.150 – 1.151)

Colour: Tan

Measurements: Length: 160–185

Width: 95–110

Description

Deutonymph:

Dorsum (Fig. 1.150 a): Propodosoma nearly triangular, bearing two pairs of equally long setae *sci* and *sce*, both arising at the same level on the propodosomal surface. Hysterosoma smooth, without any ornamentation except for the lateral shields which bear striated ornamentation. All hysterosomal setae short, smooth and pointed.

Venter (Fig. 1.150 b): Anterior apodeme of coxa I, fused along the midline to form *stI*. Apodeme II free, length exceeding the *stI*. Apodeme III short and fused. Apodeme IV also short and fused to *st2*. The sternum, *st2* extends downwards as *st3* reaching the primordium of the genital opening. *cxI*, *cxIII* and *cxIV* present as large suction discs. Genital setae, *g* present lateral to the primordial genital opening. The sucker plate present at the anal region well developed, and seen away from the posterior margin of the body. Discs, *di3*, *pd1*, *pd2* and *pd3* prominent than *b1* and *b2*.

Gnathosoma: Infracapitulum long with well distinguishable palpi, infracapitular setae present.

Legs (Fig. 1.151): Legs I and II with long and spoon shaped setae *e*. Tarsi I-IV with well developed claws. Leg chaetotaxy: Coxae: 0-0-0-0, Trochanters: 0-0-1-0, Femora: 1-1-0-1, Genua: 2-2-1-0, Tibia: 2-2-2-2, Tarsi: 7-6-6-7. Solenidiotaxy: one *ω* each present on tarsi I and II. A short famulus, *ε* present on leg I.

Adult: Not recovered during sampling.

Materials examined: 5 deutonymphs from *N. gardneri*, collected at Moolamkudam region (10°23'19.8"N 76°19'33.4"E), Thrissur Dt., Kerala, India on 18.07.2017; 3 deutonymphs from *O. obesus* collected at C.U campus (11°08'01.9"N 75°53'26.3"E), Malappuram Dt., Kerala, India on 23.08.2017, Coll. Anjitha K Bhadrar.

Habitat range: chicken manure

Remarks: The specimens examined during the study show resemblance to the species *C. manure* Eraky and Osman, 2008 collected from Egypt in all morphological features and hence fixed so. This forms the first report of the association of *C. manuri* with termites.

***Caloglyphus subterraneousi* Fakeer et al. 2014**

(Fig. 1.152 – 1.153)

Colour: Tan

Measurements: Length: 250–270

Width: 150–165

Description

Deutonymph:

Dorsum (Fig. 1.152 a): Dorsal surface of hysterosoma smooth. Propodosoma triangular in outline anteriorly and bears two pairs of equally long and smooth setae, *sce* and *sci*, the latter originating far anterior to the former. A wavy line decurrent parallel to the dorso-sejugal region on the smooth prodorsum. Dorso-sejugal region broad and ornamented with striations. Hysterosomal region smooth, and devoid of any ornamentation.

Venter (Fig. 1.152 b): Anterior apodeme of coxa I fused together forming a long sternum. Apodeme II extends towards the fused apodeme. Posterior coxal apodeme II extends medio-laterally and fused with *st1*. Anteriorcoxal apodeme III fused with the midline, apodeme IV fused with *st2*. Coxal discs *cxI*, *cxIII* and *cxIV* reduced to conoids. Apodematal setae, *2a* and *4b* present. Genital seta, *g* present, lateral to the genital opening. Anal suckers well developed, with discs *pd1*, *su*, *pd2*, *pd3* and *b2*. Median sucker, *pd1* enlarged than the lateral ones.

Gnathosoma: Infracapitulum of gnathosoma normally developed, palpal solenidia thicker and longer than the propodosomal setae.

Legs (Fig. 1.153): Legs with sickle shaped claws. Solenidion ϕ of leg I long, reaching beyond the tarsal tip. Leg chaetotaxy: Coxae: 0-0-0-0, Trochanters:0-0-1-1, Femora:

1-1-0-0, Genua: 2-2-1-1, Tibia 1-2-2-0, Tarsi: 6-8-5-6. Solenidiotaxy: one ϕ each on tibia I and II, one famulus ϵ on leg I, ω on tarsus I.

Adult: Not recovered during sampling.

Materials examined: 5 deutonymphs, from *O. feae* collected at Moolamkudam region (10°23'19.8"N 76°19'33.4"E), Thrissur Dt., Kerala, India on 18.07.2017; 5 deutonymphs from *O. obesus* collected at C.U campus (11°08'01.9"N 75°53'26.3"E), Malappuram Dt., Kerala, India on 23.08.2017; 2 deutonymphs from *O. feae* collected at Manissery region (10°46'43.1"N 76°20'26.2"E), Palakkad Dt., Kerala, India on 12.09.2017, Coll. Anjitha K Bhadrar.

Host range: *Psammotermes hypostoma*.

Remarks: The present specimens agree with the morphological features of *C. subterraneousi* Fakeer *et al.* 2014 described from Egypt. This forms the first report of the association of the species with termites in India.

Genus: *Tyrophagus* Oudemans, 1924

Generic diagnosis: Seta *ve* placed near the antero-lateral corners of the prodorsal sclerite. Seta *ve* barbed. Some of the hysterosomal setae shorter than the distance to next posterior seta. Gnathosomal supracoxal setae simple. Coxal plate well developed and broad. Grandjeans organ finger like.

Tyrophagus putrescentiae Schrank, 1781

(Fig. 1.154 – 1.55)

Colour: Transparent white

Measurements: Length: 430–480

Width: 320–350

Description

Adult female:

Dorsum (Fig. 1.154 a): Prodorsal shield punctate bearing two pairs of setae, *vi* and *ve*. Eyespots present laterally on the prodorsal shield. Three pairs of supracoxal setae, *scx*, *sce* and *sci* present, of which *scx* pectinate with six branches on either side. Opisthosomal setae whip like, except *cl*, *dl* and *d2*. Three pairs of lyrifissures, *ia*, *im* and *ip* present on the opisthosoma.

Venter (Fig. 1.154 b): Apodemes well developed for legs I and II, a thin sejugal apodeme present in between coxae II and III. Copulatory opening located posterior to anal opening. Spermathecal duct joins the base of spermathecal sac.

Gnathosoma: Gnathosoma with two segmented palpi and infracapitulum with one simple seta, *m*.

Legs: Leg chaetotaxy: Coxae: 1-0-2-1; Trochanters: 1-1-1-0; Femora: 1-1-0-1; Genua: 2(2)- 2(1)- 1(1)- 0; Tibia: 2(1)- 2(1)- 1(1)- 1(1); Tarsi: 13(4)- 12(1)- 10- 10.

Male (Fig. 1.155): Dorsal and ventral characters similar to those of the female, except for the genital region. Genital region with two pairs of genital papillae and one pair of genital setae. Anal region with three pairs of pseudoanal setae (*ps1-3*), *ps1* being the longest. Anal suckers and a pair of anal discs present at the anal region. Leg chaetotaxy and solenidiotaxy similar to that of female.

Materials examined: 3 ♀♀ and 2 ♂♂, collected from *O. rhinoceros* and from the surface of eggs of *O. rhinoceros*, at Kuzhikkani (10°22'15.3"N 76°19'15.1"E), Thrissur Dt., Kerala, India on 16.07.2017, Coll. Anjitha K Bhadran.

Habitat range: stored products, bean leaves, honey bees, bumble bees, fungi, organic materials.

Remarks: The specimens examined closely resemble the species *T. putrescentiae* described by Schrank (1781) in all features. This forms the first report on the association of this species with the adults and eggs of *O. rhinoceros*.

Genus : *Sapracarus* Fain & Philips, 1978

Generic diagnosis: Dorsal sclerite smooth and with rounded protruberances. Propodosomal sclerite normally developed with interlamellar and exobothridial setae. Genua I and II with dorsal solenidia.

Sapracarus sp.

(Fig. 1.156 – 1.157)

Colour: Transparent white

Measurements: Length: 238–243

Width: 148–153

Description**Deutonymph:**

Dorsum (Fig. 1.156 a): Dorsal surface ornamented with granulations. Dorso-sejugal region narrowing laterally and ornamented with striations medially. Propodosoma triangular with four pairs of setiform setae, *sci* longer than *vi*, *ve* and *sce*. Hysterosoma widest at the middle region, narrowing posteriorly, and bears nine pairs of setae, *d1*, *d2* and *d4* long, smooth and pointed, others short.

Venter (Fig. 1.156 b): Apodeme I short and fused with *st1*. Anterior apodeme II long, posterior apodeme II present but vestigial, not extending to the middle. Anterior apodeme III vestigial, posterior apodeme III fused medially. The sternum, *st3* present, fused to apodemes III and IV. Coxal fields I and III with coxal discs. Genital setae short, originating antero-lateral to the genital primordium. Anal sucker plate granulated, with well developed suction discs.

Gnathosoma: Infracapitulum rectangular with separate palpal region. Palpal solenidion long and thick, palpal setae short and thin.

Legs (Fig. 1.157): Legs I- IV with well developed claws. Legs I and II with spoon shaped adhesion setae and leg III with setiform seta, *e*. Leg chaetotaxy: Leg I: Fe 1- Ge 2 (1) - Ti 1 (1)- Ta 6 (4); Leg II: Ge 2 (1) - Ti 2 (1)- Ta 6 (2); Leg III: Ti 1 (1) - Ta 5; Leg IV: Fe 1- Ti 2 (1) - Ta 2. Solenidiotaxy: σ on tibia I and II, ϕ on tarsus III, A short famulus ε on tarsus I, $\omega1$ and $\omega3$ on tarsi I and II, $\omega2$ on tarsus I.

Adult: Not recovered during sampling.

Materials examined: 7 deutonymphs from *N. gardneri* collected at Moolamkudam (10°23'19.8"N 76°19'33.4"E), Thrissur Dt., Kerala, India on 02/09/2019, Coll. Anjitha K Bhadran.

Remarks: The species conforms to all the characters of the genus and hence fixed so. The genus has been reported from the nests of birds. This is the first report of the genus from termites.

4. IDENTIFICATION KEY TO THE FAMILIES/GENERA/SPECIES OF THE VARIOUS ORDERS OF MITES RECOVERED FROM THE INSECT HOSTS EXAMINED DURING THE STUDY

Key to the families / genera/species of mites (adults) collected under the Order Mesostigmata

1. Movable digit of chelicera with dendritic or brushlike excrescences; genital opening covered by latigynal and mesogynal shields in females-----Family Diplogyniidae- (2)

Movable digit of chelicera without dendritic or brushlike excrescences; genital opening covered by single shield----- (3)

2. Lateral shield with three pairs of setae-----*Tridiplogynium rhynchophora* sp. nov.

Lateral shield with two pairs of setae-----*Schizodiplogynium rhinocera* sp. nov.

3. Epigynal shield tongue shaped; peritreme sinuous; anal shield placed far way from epigynal shield -----Family Dinychidae-
Uroobovella pilosetosa Kontschan, 2012

Epigynal shield flask shaped; peritreme linear sometimes reflexed to anterior/posterior, never sinuous; anal shield adjacent to genital shield -----
------(4)

4. Sternal setae *st4* inserted on large metasternal plates; male chelicerae with spermatotreme fused to movable digit; males with apophyses on leg II; -----Family Parasitidae- -----*Holoparasitus stramenti* Karg, 1971

Sternal seta *st4* inserted on soft integument/ small metasternal plates; chelicerae of male with spermatodactyl free from movable digit; males without sexually dimorphic characters on leg II------(5)

5. All dorsal setae smooth and pointed, lateral shield not present; female with separate ventral and anal shields------(6)

Dorsal setae variously shaped, if not, setae present on lateral shield; female with ventrianal shield, if anal shield present, widely separated from epigynal shield---- (9)

6. Tectum with elongated lance like process; dorsum reticulated-----Family Eviphididae- -----***Alliphis halleri* G. R. Canestrini, 1881**

Tectum smooth or denticulate; dorsal shield without ornamentation----- (7)
-----Family Laelapidae.

7. Propodosomal setae longer than the hysterosomal setae-----***Hypoaspis sardous* (Canestrini, 1884)**

All dorsal setae more or less equal in length----- (8)

8. Sternum with lateral punctations: sternal setae *st4* and *st5* stout----***Hypoaspis subterranea* Willman, 1952**

Sternum without punctations; all sternal setae of uniform size-----***Hypoaspis heselhousi* Oudemans, 1912**

9. Arthroal brush present at the base of movable digit of chelicerae; peritreme looped proximally and join stigmata posteriorly; sperm access system not specialised in females----- (10)----- Family Macrochelidae- ***Macrocheles***

Arthroal brush absent on movable digit of chelicerae; peritreme join stigmata anteriorly; sperm access system in females well developed----- (13)

10. All dorsal setae smooth and needle like-----***Macrocheles krantzi* Evans & Hyatt, 1963**

Some dorsal setae pilose----- (11)

11. Dorsal seta *j5* pilose; sternal shield with two lineae arcuata -----***Macrocheles perglaber* Filipponi & Pegazzano, 1962**

Dorsal seta *j5* smooth; sternal shield with/ without linea arcuata----- (12)

12. Most of the dorsal setae except *j1*, *j5*, *j6*, *z1*, *z5*, *z6* and *J2* pilose; no lineae arcuata on sternum-----***Macrocheles muscaedomesticae* (Scopoli, 1772)**

Most of the dorsal setae except *j1*, *j4*, *z4* and *J5* smooth and needle like; sternum with one linea arcuata-----*Macrocheles glaber*

Muller, 1860

13. Peritrematic shield fused to exopodal plate curving behind the coxa IV; ventrianal shield broad and wedge shaped----- (14)-----

Family Blattisociidae

Peritrematic shield without the characteristic fusion as above; ventrianal shield either vase shaped or wide at the level of ZV2-----

(15)-----Family Phytoseiidae

14. Dorsal shield with 33 pairs of simple and pointed setae-----*Lasioseius confusus*
Evans, 1958

Dorsal shield with 31 pairs of setae, mostly lanceolate-----*Lasioseius moolamkudensis* sp. nov.

15. Sternal shield with median posterior projection; seta *JVI* inserted away from the anterior margin of ventrianal shield----- (16) ---Genus
Euseius

Sternal shield not as above; seta *JVI* near or on the anterior margin of ventrianal shield---(17)

16. Sternal shield longer than wide; genu III chaetotaxy 1, 1/1, 2/1, 1-----*Euseius finlandicus* (Oudemans, 1915)

Sternal shield almost as long as wide; genu III chaetotaxy 1,2/0,2/1,1-----*Euseius ovalis* Evans, 1953

17. Dorsum not ornamented; Setae *S4*, *Z5* and *Z4* longer than remaining dorsal setae----- (18) Genus *Amblyseius*

Dorsum ornamented, All dorsal setae of more or less equal in length----- (20)

18. Dorsal seta *j3* visibly longer than *j1*-----*Amblyseius largoensis*
(Muma, 1955)

Dorsal setae *j1* and *j3* of equal length----- (19)

19. Dorsal setae *Z4* and *Z5* with light serrations; ventrianal shield vase shaped-----
Amblyseius vasiformis Moraes & Mesa, 1991

Dorsal setae *Z4* and *Z5* smooth; Ventrianal shield not vase shaped, wider at level of ZV2----*Amblyseius channabasavannai* Gupta & Daniel, 1978

20. Fixed digit of chelicerae with 12 teeth-----***Transeius kroeffis* Goncalves & Ferla, 2017**

Fixed digit of chelicerae with less than six teeth-----***Neoseiulus mapuche* Ferragut & Navia, 2015**

Key to the immature stages of the various families/genera/species of Order Mesostigmata

1. Deutonymphs with well developed anal pedicel to attach arthropod cuticle; pedofossae developed----- (2)

Deutonymphs without anal pedicel; pedofossae not developed----- (8)

2. Fixed digit of chelicera with rounded apical projection, extending beyond the movable digit----- (3)-Family Dinychidae---Genus *Uroobovella*

Fixed digit of chelicera without an apical projection----- (5) Family Uropodidae

3. Ventrianal shield with more than two pairs of setae; a pair of seta present lateral to the anal fissure-----***Uroobovella assamomarginata* Hiramatsu & Hirschmann, 1979**

Ventrianal shield with two pairs of setae----- (4)

4. Sternal shield with six pairs of setae-----***Uroobovella javae* Wisneiowski, 1981**

Sternal shield with eight pairs of setae-----***Uroobovella phoenicicola* Kontschan, 2012**

5. Dorsal shield oval with wavy margins; peritreme extremely sinuate at the region adjacent to coxa I-----***Centrouropoda almerodai* Hiramatsu & Hirschmann, 1992**

Dorsal shield with solid margins; peritreme not as above---- (6)

6. Ventral and anal shields separate; sternal shield with 5-6 pairs of setae---- (7)

Ventral and anal shields fused to form ventrianal shield; sternal shield with 8 pairs of setae ----- ***Uropoda orbicularis* Muller, 1776**

7. Sternal shield heavily punctated with five pairs of setae-----***Uropoda heliocopridis* Oudemans, 1901**

Sternal shield smooth with six pairs of setae-----***Uropoda shangaica* Wisneiowski & Hirschmann, 1996**

8. Dorsal shield divided----- (9)

Dorsal shield entire----- (11)

9. Dorsal shield reticulated, with pilose setae-----Family Parasitidae-----***Poechiloichirus* sp.**

Dorsal shield not ornamented, with smooth needle like setae----- (10) Genus ***Digamasellus***

10. Dorsal shield divided into two, anterior dorsal shield with an inverted Y shape at the middle, partially overlapping the posterior shield; sternal shield with five pairs of setae-----***Digamasellus quadrisetus* (Berlese, 1921)**

Dorsal shield fragmented; sternal shield with four pairs of setae, seta *st5* off sternal shield-----***Digamasellus neodisetus* Hurlbutt, 1967**

11. Dorsal shield heavily punctated at the middle, with most of the dorsal setae present at this region; sternal setae four pairs-----Family Eviphididae--- ***Alliphis* sp.**
Dorsal shield uniformly ornamented; sternal setae four pairs----- (12) Family Laelapidae

12. All dorsal setae smooth; sternal shield broad and slightly concave----***Laelaps* sp.**
Most of the dorsal setae serrated; sternal shield acuminate-----***Dinogamasus* sp.**

Key to the families / genera of Order Trombidiformes

1. Body greatly enlarged and coloured; three pairs of legs; mouthparts adapted for parasitic mode of life----- (2) Larva Trombidiformes

Body not greatly enlarged; 3-4 pairs of legs; mouthpart not as above----- (3)

2. Coxae I and II with forked seta; gnathosoma short, not visible from the dorsal side-----Family Trombididae.....***Neosilphitrombium gratum* Fain, 1992**

Coxae I and II with barbed seta; gnathosoma subtriangular and placed anterior to prodorsum-----Family Erythracidae -----***Leptus treati* Welbourn and Jennings, 1991**

3. Leg IV of adults either absent/present, when present with fused leg segments-----

(4)

Leg IV of adults normally developed----- (6)

4. Leg IV absent; larval female with whiplike anal seta; female without bothridial sensilla; number of legs in adult females reduced to one pair ----- (5) Family Podapolipidae

Leg IV present; whip like anal seta absent in females; female with bothridial sensilla on prodorsum; number of legs four in females-----Family Tarsonemidae-
***Steneotarsonemus brasiliensis* Flechtmann, 1993**

5. Seta *hl* present; tergite D with dimples and semicircular-----
***Locustacarus chinensis* sp. nov.**

Seta *hl* absent; tergite D smooth and subtriangular-----***Podapolipus palappuramensis* sp. nov.**

6. Prodorsum with capitate bothridial sensilla laterally, dorsum clearly demarcated by more than three sclerotised tergites----- (7)

Prodorsum without bothridial sensilla; dorsal shield delineated by not more than two shields----- (11)

7. Prodorsum with one pair of trichobothria and one pair of setae----- Family Microdispidae---***Premicrodispus paramaevi* Hosseinaveh & Hajiqanbar, 2014**

Prodorsum with three pairs of setae and one pair of trichobothria----- (8)

8. Body narrow and elongate ; tarsus I with paired claws, but without empodium-----
-----Family Tarsocheylidae- ***Hoplocheylus*** --- (9)

Body stout; tarsus I with well developed empodium----- (10)

9. All dorsal idiosomal setae smooth and pointed-----***Hoplocheylus longispinus* Atyeo & Baker, 1964**

Some of the dorsal setae weakly barbed----- ***Hoplocheylus zanzibarensis* Khaustov & Ermilov, 2018**

10. Tergite C with dimples at the middle; most of the dorsal setae weakly barbed-----
-----Family Pygmephoridae-----***Pygmephorellus indicus* sp. nov.**

Tergite C smooth; all dorsal setae smooth and pointed-----
Family Dolichocybidae-----***Pavania foliata* Khaustov & Frolov, 2020.**

11. Palpi ending with strong claw; dorsum and leg segments with fan like setae-----

-Family Cheyletidae---*Cheyletus kuznetsovi* **Bochkov & Khaustov, 1999**

Palpi ending in a stout spine or sometimes with knobs, setae of legs and dorsum never fanlike----- (12) Family Cunaxidae-----Genus *Cunaxa*

12. Propodosomal shield punctated; with two pairs of setose sensilla and one pair of setiform seta----- *Cunaxa anomala* **Khaustov & Kuznetsov, 1998**

Propodosomal shield smooth; with two pairs of setose sensilla and two pairs of setae-----*Cunaxa heterostriata* **Khaustov & Kuznetsov, 1998**

Key to the adults and deutonymphs of order Sarcoptiformes

1. Anal region with well developed anal plate and suckers; mouthpart reduced---(2)----- Deutonymphal stages of Sarcoptiformes

Anal region without anal plate; mouthpart developed----- (16) Adult stages of Sarcoptiformes

2. Femora, genua and tibia of legs III and IV partially or completely fused; legs III-IV flexed anteriorly----- (3) Family Histio stomatidae

Leg III-IV without fused leg segments; not as above---- (7)

3. Anal suctorial plates well developed with five pairs of suction cups; *cxI* and *cxIII* reduced to suckers----- (4) Genus *Histio stoma*

Anal suctorial plate poorly developed; *cxI* and *cxIII* setaceous---*Curculanoetus keralensis* **sp. nov.**

4. Dorso-sejugal region narrow and reduced to a band----- (5)

Dorso-sejugal region broad and ornamented----- (6)

5. Dorsal setae 10 pairs; solenidion *ωI* of tibia II smaller than the tarsus----- *Histio stoma maritimus* (**Oudemans, 1914**)

Dorsal setae nine pairs; solenidion *ωI* of tibia II longer than the tarsus----- *Histio stoma furrowa* **sp. nov.**

6. Setae *sci* and *sce* placed in a row; seta *e* of tarsus I spoon shaped----- *Histio stoma sammari* (**Eraky, 1999**)

Seta *sci* placed anterior to *sce*; seta *e* of tarsus I setiform----- *Histio stoma herballi* **Eraky, 2017**

7. Tarsus IV with seta *e* longer than the tarsus/fused tibiotarsus; ocelli present----- (8)

Tarsus IV with seta *e* normally developed; ocelli absent----- (9)--

Deutonymphs of Family Acaridae and Family Suidasiidae

8. Coxal apodeme III free, doesnot fuse to median ventral apodeme; tarsi I-III with well developed claws-----Family Hemisarcoptidae----***Congovidia***

glossinae Fain & Elsen, 1971

Coxal apodeme III fused together; tarsi I-III with well developed ambulacrum----

Family Winterschmidtidae-----***Procalvolia sp.***

9. Dorsum granulated; anal suctorial plate placed away from the posterior margin of whose distance equal to the length of suctorial plate-----Family Suidasiidae --
Sapracarus sp.

Dorsum ornamented/ smooth; anal suctorial plate placed close to the posterior margin or displaced slightly----- (10) Family Acaridae

10. Propodosoma with two pairs of setae; dorso-sejugal region wide and ornamented----- (11)-----***Caloglyphus***

Propodosoma with more than two pairs of setae; dorso-sejugal region wide/reduced--
----- (12)

11. Hysterosoma with nine pairs of setae-----***Caloglyphus subterraneousi***
Fakeer et al. 2014

Hysterosoma with seven pairs of setae-----***Caloglyphus manuri* Eraky & Osman, 2008**

12. Propodosoma with 5 pairs of setae; hysterosoma with 11 pairs of setae----- (13)

Propodosoma with 3-4 pairs of setae; hysreosoma with 9-11 pairs of setae----- (14)

13. Seta *e* of leg III needle like; palpal setae two pairs-----***Sancassania boharti* Cross, 1968**

Seta *e* of leg III leaf like; palpal seta one pair-----***Acotyledon tariqi***
Ashfaq, Sher, Chaudhri & Aslam, 1987

14. Propodosoma with 4 pairs of setae; dorso-sejugal region narrow and band like----
--***Rhizoglyphus vicantus* Manson, 1977**

Propodosoma with 3 pairs of setae; dorso-sejugal region wide----- (15)

15. Hysterosoma with 11 pairs of setae; lateral part of hysterosoma adjacent to dorso-sejugal region with circle shaped punctations-----
Schweibea sp.

Hysterosoma with 9 pairs of setae; hysterosoma smooth-----*Acarus solimani*
Eraky, 1999

16. Femur IV with one seta; tibia I-II with two setae----Family Acaridae---
Tyrophagus putrescentiae Schrank, 1781

No seta on femur IV; tibia I-II without setae------(17)Family
 Canestriniidae

17. Dorsal seta *se* longer among all the dorsal setae; anal sucker present in male----
Canestriniella batocera sp. nov.

Dorsal seta *se* and caudal seta *cp* longer among the dorsal setae; no anal sucker in
 male----*Athogavia oryctae* sp. nov.

Table 1.4. Level and status of mite infestation on various species of insect hosts screened during the study

Sl. No	Species of insect pests	Order	Family	Status of infestation	Level of infestation
1.	<i>Oxya chinensis</i> (Thunberg, 1815)	ORTHOPTERA	Acrididae	+	**
2.	<i>Oxya hyla</i> Serville, 1831			+	**
3.	<i>Odontotermes feae</i> (Wasmann, 1896)	BLATTODEA	Termitidae	+	**
4.	<i>Odontotermes obesus</i> (Rambur, 1842)			+	**
5.	<i>Nasutitermes gardneri</i> Snyder, 1933			+	**
6.	<i>Aleurothrixus floccosus</i> (Maskell, 1896)	HEMIPTERA	Aleyrodidae	+	*
7.	<i>Bemisia tabaci</i> (Gennadius, 1889)		Aleyrodidae	+	***
8.	<i>Leptocorisa acuta</i> (Thunberg, 1783)		Alydidae	-	NA
9.	<i>Altica</i> sp.	COLEOPTERA	Chrysomelidae	+	*
10.	<i>Aulacophora foveicollis</i> (Lucas, 1849)			+	**
11.	<i>Aulacophora frontalis</i> Baly, 1888			+	*
12.	<i>Hoplasoma unicolor</i> (Illiger, 1800)				*
13.	<i>Gonocephalus</i> sp.1		Tenebrionidae	+	*
14.	<i>Gonocephalus</i> sp.2			+	*
15.	<i>Oryctes rhinoceros</i> (Linnaeus, 1758)		Scarabaeidae	+	****
16.	<i>Onitis philemon</i> Fabricius, 1801			+	**
17.	<i>Copris repertus</i> Walker, 1858			+	**
18.	<i>Catharsius molossus</i> (Linnaeus, 1758)			+	**
19.	<i>Henosepilachna vigintioctopunctata</i> (Fabricius, 1775)		Coccinellidae	+	**
20.	<i>Batocera rufomaculata</i> (De Geer, 1775)		Cerambycidae	+	**
21.	<i>Xystocera globosa</i> (Olivier, 1795)			+	*
22.	<i>Cosmopolites sordidus</i> (Germar, 1824)			+	**

23.	<i>Odoiporus longicollis</i> Oliver, 1807		Curculionidae	+	**
24.	<i>Rhynchophorus ferrugineus</i> Oliver, 1790			+	***
25.	<i>Sternochetus mangiferae</i> (Fabricius, 1775)			-	NA
26.	<i>Melanitisleda ismene</i> Linnaeus, 1758	LEPIDOPTERA	Nymphalidae		*
27.	<i>Pelopidas mathias</i> (Fabricius, 1798)		Hesperiidae	-	NA
28.	<i>Cnaphalocrocis medinalis</i> Guenee, 1854		Crambidae	-	NA
29.	<i>Scirpophaga incertulas</i> (Walker, 1863)		Pyrilidae	-	NA

‘+’-mite present, ‘-’- mite absent, ‘*’-single species of mite, ‘**’-between 2 and 5, ‘***’- between 6 and 10, ‘*****’-more than 10.

Table 1.5. Systematic details of acarine taxa associated with the insect pests examined during the study

Sl. No.	DETAILS OF MITE ASSOCIATES							DETAILS OF INSECT HOSTS		Known host range of mites	Taxonomic status
	Mite species	Genus	Family	Superfamily	Suborder	Order	Superorder	Host insect species	Order/Family of host insect		
1	<i>Tridiplogynium rhynchophora</i> sp. nov.	<i>Tridiplogynium</i> Tragardh, 1950	Diplogyniidae Tragardh, 1950	Celaenopsoidea Tragardh, 1950	Trigynaspida Camin & Gorirossi, 1955	Mesostigmata G. Canestrini, 1891	Parasitiformes Reuter, 1909	<i>Rhynchophorus ferrugineus</i> Oliver, 1790	Coleoptera: Curculionidae	-----	New to science
2	<i>Schizodiplogynium rhinocera</i> sp. nov.	<i>Schizodiplogynium</i> Tragardh, 1950	”	”	”	”	”	<i>Oryctes rhinoceros</i> Linnaeus, 1758	Coleoptera: Scarabaeidae	-----	”
3	<i>Uropoda heliocopridis</i> Oudemans, 1901	<i>Uropoda</i> Latreille, 1805	Uropodidae Kramer, 1881	Uropodoidea Kramer, 1881	Monogynaspida Camin and Gorirossi, 1955	”	”	”	”	<i>Coprini</i> sp.	First report from <i>O. rhinoceros</i> . First report from India

4	<i>Uropoda orbicularis</i> Muller, 1776	”	”	”	”	”	”	<i>Batocera rufomaculata</i> De Geer, 1775	Coleoptera: Cerambycidae	<i>Rhynchophorus ferrugineus</i> , coprophagous beetles.	First report from <i>B. rufomaculata</i> . First report from India
5	<i>Uropoda shangaica</i> Wisneiowski & Hirschmann, 1996	”	”	”	”	”	”	<i>Xystocera globosa</i> Oliver, 1795	”	<i>Coprini</i> sp.	First report from <i>Xystocera globosa</i> . First report from India
6	<i>Centrouropoda almerodai</i> Hiramatsu & Hirschmann, 1992	<i>Centrouropoda</i> Berlese, 1917	”	”	”	”	”	<i>Rhynchophorus ferrugineus</i> Oliver, 1790	Coleoptera: Curculionidae	<i>Rhynchophorus ferrugineus</i>	First report from India
7	<i>Uroobovella assamomarginata</i> Hiramatsu & Hirschmann, 1979	<i>Uroobovella</i> Berlese, 1903	Dinychidae Berlese, 1916	”	”	”	”	”	”	”	First report from India
8	<i>Uroobovella javae</i> Wisneiowski, 1981	”	”	”	”	”	”	”	”	”	First report from India
9	<i>Uroobovella phoenicicola</i> Kontschan, 2012	”	”	”	”	”	”	”	”	<i>Rhynchophorus phoenicis</i>	First report from <i>R. ferrugineus</i> . First report from India
10	<i>Uroobovella pilosetosa</i> Kontschan, 2012	”	”	”	”	”	”	<i>Onitis philemon</i> Fabricius, 1801	Coleoptera: Scarabaeidae	Drift wood	First report from class Insecta. First

											report from India
11	<i>Holoparasitus stramenti</i> Karg, 1971	<i>Holoparasitus</i> Oudemans, 1936	Parasitidae Oudemans, 1901	Parasitoidea Oudemans, 1901	”	”	”	<i>Copris repertus</i> Walker, 1858, <i>O. rhinoceros</i> grub	Coleoptera: Scarabaeidae	Leaf litter, compost, moss	First report from India
12.	<i>Poechilocheirus</i> sp.	<i>Poechilocheirus</i> G. & R. Canestrini, 1882	”	”	”	”	”	<i>Copris repertus</i> Walker, 1858.	Coleoptera: Scarabaeidae	<i>Bubas bubalus</i> , <i>Geotrupes spiniger</i> , <i>Onthophagus vacca</i> , <i>Gymnopleurus mopsus</i> , <i>Copris hispanus</i>	First report from order Coleoptera. First report from India
13.	<i>Digamasellus neodisetus</i> Hurlbutt, 1967	<i>Digamasellus</i> Berlese, 1905	Digamasellidae Evans, 1957	Rhodacaroida Oudemans, 1902	”	”	”	<i>O. rhinoceros</i> grub	Coleoptera: Scarabaeidae	<i>Hylurgopinus rufipes</i> , <i>Dendroctonus frontalis</i>	First report from <i>O. rhinoceros</i> . First report from India
14.	<i>Digamasellus quadrisetus</i> Berlese, 1921	”	”	”	”	”	”	<i>R. ferrugineus</i> Oliver, 1790	Coleoptera: Curculionidae	<i>Ips tyrophagus</i>	First report from <i>R. ferrugineus</i> . First report from India
15.	<i>Alliphis halleri</i> G. R. Canestrini, 1881	<i>Alliphis</i> Halbert, 1923	Eviphididae Berlese, 1913	Eviphidoidea Berlese, 1913	”	”	”	<i>Melanitis leda ismene</i> Linnaeus, 1758	Lepidoptera: Nymphalidae	<i>Bubas bubalus</i> , <i>Geotrupes spiniger</i> , <i>Onthophagus vacca</i> , <i>Gymnopleurus mopsus</i> , <i>Copris</i>	First report from Lepidoptera. First report from India

										hispanus, leaf compost, grass compost	
16.	<i>Alliphis</i> sp.	”	”	”	”	”	”	<i>Catharsius molossus</i> Linanaeus, 1758	Coleoptera: Scarabaeidae	<i>Bubas bubalus</i> , <i>Geotrupes spiniger</i> , <i>Onthophagus vacca</i> , <i>Gymnopleuru s mopsus</i> , <i>Copris hispanus</i> , Lepidoptera	First report from <i>C. molossus</i> . First report of the genus from Kerala
17.	<i>Macrocheles glaber</i> Muller, 1860	<i>Macrochel es</i> Latreille, 1829	Macrocheli dae Vitzthum, 1930	”	”	”	”	<i>Onitis philemon</i> Fabricius, 1801	Coleoptera: Scarabaeidae	Moss, lichen, bark, soil, straw, dung, litter under <i>Pinus</i> sp., <i>Pyrus</i> sp., <i>Salix</i> sp.	First report from class Insecta. First report from India
18.	<i>Macrocheles krantzi</i> Anwarullah & Irshad, 1971	”	”	”	”	”	”	<i>Copris repertus</i> Walker, 1858, <i>R. ferrugineus</i> grub	Coleoptera: Scarabaeidae, Curculionidae	<i>Scarabaeus brahminus</i> , <i>Scarabaeus erichsoni</i> , soil	First report from <i>R. ferrugineus</i> . First report from India
19.	<i>Macrocheles muscaedomesti cae</i> Scopoli, 1772	”	”	”	”	”	”	<i>Odoiporus longicollis</i> Marshall, 1830, <i>Cosmopolites sordidus</i> Germar, 1824	Coleoptera: Curculionidae	<i>Musca domestica</i> , <i>Stomoxyscalc itrans</i> , bumblebees, honeybees, soil	First report from order Coleoptera. First report from Kerala

20.	<i>Macrocheles perglaber</i> Filipponi & Pegazzano, 1962	”	”	”	”	”	”	Grubs of <i>Oryctes rhinoceros</i> , <i>R. ferrugineus</i> Oliver, 1790	Coleoptera: Scarabaeidae, Curculionidae	Dung, straw, weeds	First report from class Insecta. First report from India
21.	<i>Amblyseius channabasavanai</i> Gupta & Daniel, 1978	<i>Amblyseius</i> Berlese, 1914	Phytoseiidae Berlese, 1916	Phytoseioides Berlese, 1916	”	”	”	<i>Bemisia tabaci</i> Gennadius, 1889	Hemiptera: Aleyrodidae	Mango, jute, citrus, neem, undet, champa, <i>Shorea robusta</i> , <i>Lantana</i> , chrysanthemum, Dahlia.	First report from chilli infested with <i>B. tabaci</i> .
22.	<i>Amblyseius largoensis</i> Muma, 1955	”	”	”	”	”	”	<i>Aleurothrixus floccosus</i> Maskell, 1896, <i>B. tabaci</i> Gennadius, 1889	Hemiptera: Aleyrodidae	<i>Mangifera indica</i> , <i>Calophyllum inophyllum</i> , <i>Musandra corymbosa</i> , <i>Tabernaemontana coronaria</i> , <i>Tectona grandis</i> , <i>Dalbergia</i> , beans, citrus, pomegranate, black berry, sugarcane, <i>Cassia</i> , cashewnut, bamboo, arecanut, fig,	First report from chilli infested with <i>B. tabaci</i> .

										guava, chilli, <i>Shorea</i> sp., papaya, pepper, dahlia, china rose, poppy, pine cone, grass, dahlia, <i>Citrus</i> <i>medica</i> , <i>Mallotus</i> sp., <i>Alstonia</i> <i>scholaris</i> , <i>Anona</i> <i>squamosa</i> , <i>Calotropis</i> , <i>Suaeda</i> <i>nufiflora</i> , <i>Jasminum</i> <i>sambac</i> , <i>Basicophia</i> <i>javanica</i> , <i>Phoenix</i> <i>paludosa</i> , <i>Shorea</i> <i>robusta</i> , banyan, peach, sapota, jackfruit, cotton, tea, arum, predatory on mites, thrips and whitefly	
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23.	<i>Amblyseius vasiformis</i> Moraes & Mesa, 1991	”	”	”	”	”	”	<i>Bemisia tabaci</i> Gennadius, 1889	Hemiptera: Aleyrodidae	<i>Bixa orellana</i> , <i>Carica papaya</i> , <i>Citrus</i> sp., <i>Coffea</i> sp., <i>Cocos nucifera</i> , <i>C. aurantifolia</i> , <i>C. reticulata</i> , <i>Jatropha biagossypiens</i> <i>e</i> , <i>Matisia cordata</i> , <i>Pisidium guajava</i> , <i>Mangifera indica</i> , <i>Manihot esculenta</i> , <i>Morchella esculenta</i> , <i>Malvaviscus penduliflorus</i> , <i>Threobroma cacao</i> , <i>Solanum caricaefolium</i>	First report from chilli infested with <i>B. tabaci</i>
24.	<i>Neoseiulus mapuche</i> Ferragut & Navia, 2015	<i>Neoseiulus</i> Hughes, 1948	”	”	”	”	”	<i>Oxya hyla</i> Serville, 1831	Orthoptera: Acrididae	<i>Saxegothaea conspicua</i>	First report from class Insecta. First report from India

25.	<i>Euseius finlandicus</i> Oudemans, 1915	<i>Euseius</i> De Leon, 1967	”	”	”	”	”	<i>Bemisia tabaci</i> Gennadius, 1889	Hemiptera: Aleyrodidae	Maize, chinar, grape, tea, peach, pine, citrus, apple, castor, bamboo, cotton, arum, cashewnut, palm, coconut, datepalm, fig, banana, orchid, cardamom, lemon, mango, mulberry, chrysanthemum, <i>Shorea robusta</i> , <i>Amaranthus</i> , <i>Ipomoea</i> , <i>Ficus racemosa</i> , <i>Pyrus communis</i> .	First report from chilli infested with <i>B. tabaci</i>
26.	<i>Euseius ovalis</i> Evans, 1953	”	”	”	”	”	”	”	”	Ficus, <i>Terminalia arjuna</i> , banana, <i>Vitex pubescens</i> , napier grass, castor, mango, coconut,	First report from chilli infested with <i>B. tabaci</i>

										paddy, sugarcane, cashewnut, oilseed plant, <i>Bauhinia purpuria</i> , chilli, arum, undet, cotton, brinjal, date palm, guava, <i>Macrocospa niculatus</i> , <i>Holorrhena antidysenteric a</i> , <i>Tabernae montana</i> , <i>Cassia fistula</i> , <i>Dolichos lablab</i> , <i>Glycosmis pentaphylla</i> , <i>Bougainvillae spectabilis</i> , <i>Luffa acutangula</i> .	
27.	<i>Transeius kroeffis</i> Goncalves & Ferla, 2017	<i>Transeius</i> Chant & McMurtry, 2004	”	”	”	”	”	”	”	<i>Dicksonia sellowiana</i> , <i>Myrcia retorta</i> , <i>Solan umsantaeacat harinae</i>	First report from chilli infested with <i>B. tabaci</i> . First report from India
28.	<i>Lasioseius confuses</i> Evans, 1958	<i>Lasioseius</i> Berlese, 1916	Blattisociid ae Garman, 1948	”	”	”	”	<i>Oryctes rhinoceros</i> Linnaeus, 1758	Coleoptera: Scarabaeidae	soil, maple swamp	First report from class Insecta. First

											report from India
29.	<i>Lasioseius moolamkudensis</i> sp. nov.	”	”	”	”	”	”	<i>Bemisia tabaci</i> Gennadius, 1889	Hemiptera: Aleyrodidae	-	New to science
30.	<i>Laelaps</i> sp.	<i>Laelaps</i> Koch, 1836	Laelapidae Berlese, 1892	Dermanyssoidea Kolenati, 1815	”	”	”	<i>Oryctes rhinoceros</i> grub	Coleoptera: Scarabaeidae	rodents, ants, higher mammals	First report from Coleoptera. First report of the genus from Kerala
31.	<i>Hypoaspis heselhousei</i> Oudemans, 1912	<i>Hypoaspis</i> G. Canestrini, 1884	Laelapidae Berlese, 1892	”	”	”	”	<i>Catharsius molossus</i>	Coleoptera: Scarabaeidae	leaf litter, soil and mammals	First report from class Insecta. First report from India
32.	32. <i>Hypoaspis sardous</i> Berlese, 1911	”	”	”	”	”	”	<i>Oryctes rhinoceros</i> Linnaeus, 1758	”	nests of arthropods and insects	First report from <i>O. rhinoceros</i> . First report from India
33.	<i>Hypoaspis subterranean</i> Willman, 1952	”	”	”	”	”	”	<i>Copris repertus</i>	”	coprophagous beetles	First report from India
34.	<i>Dinogamasus</i> sp.	<i>Dinogamasus</i> Kramer, 1898	”	”	”	”	”	<i>Rhynchophorus ferrugineus</i> Oliver, 1790	Coleoptera: Curculionidae	Carpenter bees	First report from Coleoptera. First report of the genus from Kerala
35.	<i>Cunaxa anomala</i> Khaustov & Kuznetsov, 1998	<i>Cunaxa</i> Von Heyden, 1826	Cunaxidae Thor, 1902	Bdelloidea Duges, 1834	Prostigmata Kramer, 1877	Trombidiformes Reuter, 1909	Acariformes Zakhvatkin, 1952	<i>Bemisia tabaci</i> Gennadius, 1889	Hemiptera: Aleyrodidae	Persimmon	First report from chilli infested with <i>B. tabaci</i> .

											First report from India
36.	<i>Cunaxa heterostriata</i> Khaustov & Kuznetsov, 1998	”	”	”	”	”	”	”	”	Lichen	First report from chilli infested with <i>B. tabaci</i> . First report from India
37.	<i>Leptus treati</i> Welbourn and Jennings, 1991	<i>Leptus</i> Latreille, 1795	Erythraeidae Oudemans, 1992	Erythraeoides Grandjean, 1947	”	”	”	<i>Oxya hyla</i> Serville, 1831, <i>Oxya chinensis</i> Thunberg, 1815	Orthoptera: Acrididae	<i>Choristoneura fumijerana</i>	First report from <i>O. hyla</i> . First report from India
38.	<i>Neosilphitrombium gratum</i> Fain, 1992	<i>Neosilphitrombium</i> Fain, 1992	Trombidiidae Leach, 1815	Trombidioides Leach, 1815	”	”	”	<i>B. rufomaculata</i> De Geer, 1775	Coleoptera: Cerambycidae	Carrion beetle	First report from Cerambycidae. First report from India
39.	<i>Cheyletus kuznetsovi</i> Bochkov & Khaustov, 1999	<i>Cheyletus</i> Latreille, 1796	Cheyletidae Leach, 1815	Cheyletoidea Leach, 1815	”	”	”	<i>Gonocephalus</i> sp.1	Coleoptera: Tenebrionidae	Stored product, soil-litter	First report from class Insecta. First report from India
40.	<i>Hoplocheylus longispinus</i> Atyeo & Baker, 1964	<i>Hoplocheylus</i> Atyeo & Baker, 1964	Tarsocheylidae Berlese, 1904	Tarsocheylidea Atyeo & Baker, 1964	”	”	”	<i>Gonocephalus</i> sp.2	”	moss and rotten wood	First report from class Insecta. First report from India
41.	<i>Hoplocheylus anzibarensis</i> Khaustov & Ermilov, 2018	”	”	”	”	”	”	<i>Onitis philemon</i>	Coleoptera: Scarabaeidae	litter	First report from class Insecta. First report from India

42.	<i>Pavania foliata</i> Khaustov & Frolov, 2020	<i>Pavania</i> Lombardini, 1949	Dolichocybidae Mahunka, 1970	Dolichocyboidea Mahunka, 1970	"	"	"	<i>Catharsius molossus</i>	Coleoptera: Scarabaeidae	<i>Scarabaeus typhon</i>	First report from <i>Catharsius molossus</i> . First report from India
43.	<i>Premicrodispus paramaevi</i> Hosseini-Naveh & Hajiqanbar, 2014	<i>Premicrodispus</i> Cross, 1965	Microdispidae Cross, 1965	Pygmephoridea Cross, 1965	"	"	"	<i>Odontotermes feae</i> Wasmann, 1896	Blattodea: Termitidae	<i>Lucanus ibericus</i>	First report from order Blattodea. First report from India
44.	<i>Pygmephorellus indicus</i> sp. nov.	<i>Pygmephorellus</i> Cross & Moser, 1971	Pygmephoridae Cross, 1965	"	"	"	"	<i>Copris repertus</i>	Coleoptera: Scarabaeidae	-	New to science
45.	<i>Steneotarsonemus brasiliensis</i>	<i>Steneotarsonemus</i> Beer, 1954	Tarsonemidae Kramer, 1877	Tarsonemoidae Canestrini & Fanzago, 1877	"	"	"	<i>Oxya hyla</i> Serville, 1831	Orthoptera: Acrididae	<i>Saccharum officinarum</i>	First report from class Insecta. First report from India
46.	<i>Podapolipus palappuramensis</i> sp. nov.	<i>Podapolipus</i> Rovelli & Grassi, 1888	Podapolipidae Ewing, 1922	"	"	"	"	"	"	-	New to science
47.	<i>Locustacarus chinensis</i> sp. nov.	<i>Locustacarus</i> Ewing, 1924	"	"	"	"	"	<i>Oxya chinensis</i> Thunberg, 1815	"	-	New to science
48.	<i>Histiostoma herali</i> Eraky, 2017		Histiostomatidae Berlese, 1897	Histiostomatoidae Berlese, 1897	Oribatida (Duges, 1833)	Sarcoptiformes Reuter, 1909	"	<i>Odontotermes obesus</i> , Rambur, 1842	Blattodea: Termitidae	<i>Cynodon dactylon</i>	First report from class Insecta. First report from India
49.	<i>Histiostoma maritimus</i>	<i>Histiostoma</i> Kramer, 1876	"	"	"	"	"	<i>Henosepilachna vigintioctopunctata</i> , Altica sp.	Coleoptera: Coccinellidae Chrysomelidae	Not available	First report from Chrysomelid

	Oudemans, 1914										ae. First report from India
50.	<i>Histiostoma sammari</i> Eraky, 1999	”	”	”	”	”	”	<i>Oryctes rhinoceros</i> Linnaeus, 1758, <i>Aulacophora foveicollis</i> , <i>Aulacophora frontalis</i>	Coleoptera: Scarabaeidae, Chrysomelidae	Termite nest	First report from Coleoptera. First report from India
51.	<i>Histiostoma furrowa</i> sp. nov.	”	”	”	”	”	”	<i>Odoiporus longicollis</i> Fabricius 1792, <i>C. sordidus</i> Germar, 1824	Coleoptera: Curculionidae	-	New to science
52.	<i>Curculanoetus keralensis</i> sp. nov.	”	”	”	”	”	”	<i>Rhynchophorus ferrugineus</i> Oliver, 1790	”	-	New to science
53.	<i>Canestriniella batocera</i> sp. nov.	<i>Canestriniella</i> Berlese, 1910	Canestriniidae Berlese, 1884	Canestrinioides Berlese, 1884	”	”	”	<i>Batocera rufomaculata</i>	Coleoptera: Cerambycidae	-	New to science
54.	<i>Athogavia oryctae</i> sp. nov.	<i>Athogavia</i> Haitlinger, 1989	”	”	”	”	”	<i>Oryctes rhinoceros</i> Linnaeus, 1758	Coleoptera: Scarabaeidae	-	New to science
55.	<i>Congovidia glossinae</i> Fain & Elsen, 1971	<i>Congovidia</i> Fain & Elsen, 1971	Hemisarcopidae Lignieres, 1893	Hemisarcopidae Oudemans, 1908	”	”	”	<i>Henosepilachna vigintioctopunctata</i>	Coleoptera: Coccinellidae	Bees	First report from Coleoptera. First report from India
56.	<i>Procalvolia</i> sp.	<i>Procalvolia</i> Fain, 1971	Winterschmidtidae	”	”	”	”	<i>Aulacophora foveicollis</i> ,	Coleoptera: Chrysomelidae	Carpenter bees, honey bees	First report from Coleoptera.

			Oudemans, 1923					<i>Hoplasoma unicolor</i>			First report from India
57.	<i>Acarus solimani</i> Eraky, 1999	<i>Acarus</i> Linnaeus, 1758	Acaridae Latreille, 1802	Acarioidea Latreille, 1802	”	”	”	<i>Nasutitermes gardneri</i>	Blattodea: Termitidae	Stored product, termites	First report from <i>N.gardneri</i> . First report from India
58.	<i>Rhizoglyphus vicantus</i> Manson, 1977	<i>Rhizoglyphus</i> Claparede, 1869	”	”	”	”	”	<i>O.dontotermes obesus</i> Rambur, 1842, <i>O. feae</i> Wasmann, 1896	”	Leaf litter	First report from class Insecta. First report from India
59.	<i>Acotyledon tariqi</i> Ashfaq et al., 1987	<i>Acotyledon</i> Oudemans, 1903	”	”	”	”	”	<i>Nasutitermes gardneri</i> Snyder, 1933, <i>O. rhinoceros</i> egg	”	Chick pea	First report from class Insecta. First report from India
60.	<i>Sancassania boharti</i> Cross, 1968	<i>Sancassania</i> Oudemans, 1916	”	”	”	”	”	<i>Oryctes rhinoceros</i> Linnaeus, 1758, <i>O. obesus</i> Rambur, 1842	Coleoptera: Scarabaeidae	<i>Nomia melanderi</i> , diplopods, millipedes	First report from India
61.	<i>Schweibea</i> sp.	<i>Schweibea</i> Oudemans, 1916	”	”	”	”	”	<i>Odontotermes feae</i> Wasmann, 1896	Blattodea: Termitidae	Litter, fungi, decaying trees, <i>Hylobiusabietis</i> , <i>Ectemnius guttatus</i> , <i>Platycera scaraboides</i> , <i>Laphra flava</i>	First report from order Blattodea. First report of the genus from India

62.	<i>Caloglyphus manuri</i> Eraky & Osman, 2008	<i>Caloglyphus</i> Berlese, 1923	”	”	”	”	”	<i>Nasutitermes gardneri</i> Snyder, 1933	”	Chicken manure	First report from order Blattodea. First report from India
63.	<i>Caloglyphus subterraneus</i> Fakeer <i>et al.</i> 2014	”	”	”	”	”	”	<i>Odontotermes feae</i> Wasmann, 1896, <i>O. obesus</i> Rambur, 1842	”	<i>Psammotermes hypostoma</i>	First report from <i>Odontotermes</i> . First report from India
64.	<i>Tyrophagus putrescentiae</i> Schrank, 1781	<i>Tyrophagus</i> Oudemans, 1924	”	”	”	”	”	<i>Oryctes rhinoceros</i> Linnaeus, 1758	Coleoptera: Scarabaeidae	Stored products, honeybees, bumble bees	First report from Coleoptera.
65.	<i>Sapracarus</i> sp.	<i>Sapracarus</i> Fain & Philips, 1978	Suidasiidae	”	”	”	”	<i>Nasutitermes gardneri</i> Snyder, 1933	Blattodea: Termitidae	Manure, fungi	First report from order Blattodea. First report of the genus from India

Table 1.6. New species of mites recovered during the study

Mite species	Order	Super family	Family	Host insect
1. <i>Tridiplogynium rhynchophora</i> sp. nov.	Mesostigmata	Celaenopsoid ea	Diplogyniidae	<i>Rhynchophorus ferrugineus</i>
2. <i>Schizodiplogynium rhinocera</i> sp. nov.	Mesostigmata	Celaenopsoid ea	Diplogyniidae	<i>Oryctes rhinoceros</i>
3. <i>Lasioseius moolamkudensis</i> sp. nov.	Mesostigmata	Phytoseioidea	Blattisociidae	<i>Bemisia tabaci</i> on chilli
4. <i>Pygmephorus indicus</i> sp. nov.	Trombidiformes	Pygmephorodea	Pygmephoridae	<i>Copris repertus</i>
5. <i>Podapolipus palappuramensis</i> sp. nov.	Trombidiformes	Tarsonemoid ea	Podapolipidae	<i>Oxya hyla</i>
6. <i>Locustacarus chinensis</i> sp. nov.	Trombidiformes	Tarsonemoid ea	Podapolipidae	<i>Oxya chinensis</i>
7. <i>Histiostoma furrowa</i> sp. nov.	Sarcoptiformes	Histiostomat oidea	Histiostomati dae	<i>Odoiporus longicollis</i>
8. <i>Curculanoetus keralensis</i> sp. nov.	Sarcoptiformes	Histiostomat oidea	Histiostomati dae	<i>Rhynchophorus ferrugineus</i>
9. <i>Canestriniella batocera</i> sp. nov.	Sarcoptiformes	Canestriniodea	Canestriniidae	<i>Batocera rufomaculata</i>
10. <i>Athogavia oryctae</i> sp. nov.	Sarcoptiformes	Canestriniodea	Canestriniidae	<i>Oryctes rhinoceros</i>

Table 1.7. Incidence and relative abundance of the various taxa of mites on the body of insect hosts

Sl.No.	Insect species screened	Acarine taxa harboured by insect hosts			Percentage of abundance (%)
		No. of families	No. of genera	No. of species	
1.	<i>Oxya chinensis</i>	2	2	2	2.53
2.	<i>Oxya hyla</i>	4	4	4	5.06
3.	<i>Odontotermes feae</i>	2	4	4	5.06
4.	<i>Odontotermes obesus</i>	1	3	3	3.79
5.	<i>Nasutitermes gardneri</i>	2	4	4	5.06
6.	<i>Aleurothrixus floccosus</i>	1	1	1	1.26
7.	<i>Bemisia tabaci</i>	3	5	9	11.39
8.	<i>Altica</i> sp.	1	1	1	1.26
9.	<i>Aulacophora foveicollis</i>	2	2	2	2.53
10.	<i>Aulacophora frontalis</i>	1	1	1	1.26
11.	<i>Batocera rufomaculata</i>	3	3	3	3.79
12.	<i>Cosmopolites sordidus</i>	2	2	2	2.53
13.	<i>Gonocephalus</i> sp.1	1	1	1	1.26
14.	<i>Gonocephalus</i> sp.2	1	1	1	1.26
15.	<i>Henosepilachna vigintioctopunctata</i>	2	2	2	2.53
16.	<i>Hoplasoma unicolor</i>	1	1	1	1.26
17.	<i>Odoiporus longicollis</i>	2	2	2	2.53
18.	<i>Oryctes rhinoceros</i>	11	13	13	16.45
19.	<i>Rhynchophorus ferrugineus</i>	7	7	10	12.65
20.	<i>Xystocera globosa</i>	1	1	1	1.26
21.	<i>Onitis philemon</i>	3	3	3	3.79
22.	<i>Copris repertus</i>	4	5	5	6.32
23.	<i>Catharsius molossus</i>	3	3	3	3.79
24.	<i>Melanitis leda ismene</i>	1	1	1	1.26

Table 1.8. Life stages of mites associated with insect hosts and the nature of their association

Sl. No.	Species of insect hosts	Mite species associated with insect hosts	Life stage(s) of mites associated with insect hosts	Nature of association between mites and their insect hosts
1.	<i>Oxya chinensis</i>	1. <i>Leptus treati</i>	Larva	Ectoparasitic
		2. <i>Locustacarus chinensis</i> sp. nov.	Egg, larval female	Ectoparasitic
2.	<i>Oxya hyla</i>	1. <i>Neoseiulus mapuche</i>	Adult male	Phoretic
		2. <i>Leptus treati</i>	Larva	Ectoparasitic
		3. <i>Steneotarsonemus brasiliensis</i>	Adult female	Phoretic
		4. <i>Podapolipus palappuramensis</i> sp. nov.	Egg, larval female, Adult male and female	Ectoparasitic
3.	<i>Odontotermes feae</i>	1. <i>Premicrodispus paramaevi</i>	Adult female	Phoretic
		2. <i>Rhizoglyphus vicantus</i>	Deutonymph	Phoretic
		3. <i>Schweibea</i> sp.	Deutonymph	Phoretic
		4. <i>Caloglyphus subterraneousi</i>	Deutonymph	Phoretic
4.	<i>Odontotermes obesus</i>	1. <i>Rhizoglyphus vicantus</i>	Deutonymph	Phoretic
		2. <i>Sancassania boharti</i>	Deutonymph	Phoretic
		3. <i>Histiostoma herbali</i>	Deutonymph	Phoretic
5.	<i>Nasutitermes gardneri</i>	1. <i>Acarus solimani</i>	Deutonymph	Phoretic
		2. <i>Acotyledon tariqi</i>	Deutonymph	Phoretic
		3. <i>Caloglyphus manuri</i>	Deutonymph	Phoretic
		4. <i>Sapracarus</i> sp.	Deutonymph	Phoretic
6.	<i>Aleurothrixus floccosus</i>	1. <i>Amblyseius largoensis</i>	Adult male and female	Predatory

7.	<i>Bemisia tabaci</i>	1. <i>Amblyseius channabasavanni</i>	Adult female	Predatory
		2. <i>Amblyseius largoensis</i>	Adult male and female	Predatory
		3. <i>Amblyseius vasiformis</i>	Adult female	Predatory
		4. <i>Euseius finlandicus</i>	Adult female	Predatory
		5. <i>Euseius ovalis</i>	Adult female	Predatory
		6. <i>Transeius kroeffis</i>	Adult male and female	Predatory
		7. <i>Lasioseius moolamkudensis</i> sp. nov.	Adult male and female	Predatory
		8. <i>Cunaxa anomala</i>	Adult female	Predatory
		9. <i>Cunaxa heterostriata</i>	Adult female	Predatory
8.	<i>Altica</i> sp.	1. <i>Histiostoma maritimus</i>	Deutonymph	Phoretic
9.	<i>Aulacophora foveicollis</i>	1. <i>Histiostoma sammari</i>	Deutonymph	Phoretic
		2. <i>Procalvolia</i> sp.	Deutonymph	Phoretic
10.	<i>Aulacophora frontalis</i>	1. <i>Histiostoma sammari</i>	Deutonymph	Phoretic
11.	<i>Batocera rufomaculata</i>	1. <i>Uropoda orbicularis</i>	Deutonymph	Phoretic
		2. <i>Neosilphitrombium gratum</i>	Larva	Ectoparasitic
		3. <i>Canestriniella batocera</i> sp. nov.	Egg-Adult	Ectoparasitic
12.	<i>Cosmopolites sordidus</i>	1. <i>Macrocheles muscaedomesticae</i>	Adult female	Phoretic
		2. <i>Histiostoma furrowa</i> sp. nov.	Deutonymph	Phoretic
13.	<i>Gonocephalus</i> sp.1	1. <i>Cheyletus kuznetsovi</i>	Adult female	Phoretic
14.	<i>Gonocephalus</i> sp.2	1. <i>Hoplocheylus longispinus</i>	Adult female	Phoretic
15.	<i>Henosepilachna vigintioctopunctata</i>	1. <i>Histiostoma maritimus</i>	Deutonymph	Phoretic
		2. <i>Congovidia glossinae</i>	Deutonymph	Phoretic
16.	<i>Hoplasoma unicolor</i>	1. <i>Procalvolia</i> sp.	Deutonymph	Phoretic
17.	<i>Odoiporus longicollis</i>	1. <i>Macrocheles muscaedomesticae</i>	Adult female	Phoretic
		2. <i>Histiostoma furrowa</i> sp. nov.	Deutonymph	Phoretic, Necromenic
18.	<i>Oryctes rhinoceros</i>	1. <i>Schizodiplogynium rhinocera</i> sp. nov.	Adult male and female	Phoretic

		2. <i>Uropoda heliocopridis</i>	Deutonymph	Phoretic
		3. <i>Holoparasitus stramenti</i>	Adult male	Phoretic
		4. <i>Digamasellus neodisetus</i>	Protonymph	Phoretic
		5. <i>Macrocheles perglaber</i>	Adult female	Phoretic
		6. <i>Lasioseius confusus</i>	Adult female	Phoretic
		7. <i>Laelaps</i> sp.	Deutonymph	Phoretic
		8. <i>Hypoaspis sardous</i>	Adult female	Phoretic
		9. <i>Histiostoma sammari</i>	Deutonymph	Phoretic
		10. <i>Athogavia oryctae</i> sp. nov.	Egg-Adult	Ectoparasitic
		11. <i>Acotyledon tariqi</i>	Deutonymph	Phoretic
		12. <i>Sancassania boharti</i>	Deutonymph	Phoretic
		13. <i>Tyrophagus putrescentiae</i>	Egg-Adult	Ectoparasitic
19.	<i>Rhynchophorus ferrugineus</i>	1. <i>Tridiplogynium rhynchophora</i> sp.nov.	Adult female	Phoretic
		2. <i>Centrouropoda almerodai</i>	Deutonymph	Phoretic
		3. <i>Uroobovella assamomarginata</i>	Deutonymph	Phoretic
		4. <i>Uroobovella javae</i>	Deutonymph	Phoretic
		5. <i>Uroobovella phoenicicola</i>	Deutonymph	Phoretic
		6. <i>Digamasellus quadrisetus</i>	Deutonymph	Phoretic
		7. <i>Macrocheles krantzi</i>	Adult female	Phoretic
		8. <i>Macrocheles perglaber</i>	Adult female	Phoretic
		9. <i>Dinogamasus</i> sp.	Deutonymph	Phoretic
		10. <i>Curculanoetus keralensis</i> sp. nov.	Deutonymph	Phoretic
20.	<i>Xystocera globosa</i>	1. <i>Uropoda shangaica</i>	Deutonymph	Phoretic
21.	<i>Onitis philemon</i>	1. <i>Uroobovella pilosetosa</i>	Adult female	Phoretic
		2. <i>Macrocheles glaber</i>	Adult female	Phoretic
		3. <i>Hoplocheylus zanzibarensis</i>	Adult female	Phoretic
22.	<i>Copris repertus</i>	1. <i>Holoparasitus stramenti</i>	Adult male	Phoretic

		2. <i>Poecilochirus</i> sp.	Deutonymph	Phoretic
		3. <i>Macrocheles krantzi</i>	Adult female	Phoretic
		4. <i>Hypoaspis subterranea</i>	Adult female	Phoretic
		5. <i>Pygmephorus indicus</i> sp. nov.	Adult female	Phoretic
23.	<i>Catharsius molossus</i>	1. <i>Alliphis</i> sp.	Deutonymph	Phoretic
		2. <i>Hypoaspis heselhousei</i>	Adult female	Phoretic
		3. <i>Pavania foliata</i>	Adult female	Phoretic
24.	<i>Melanitis leda ismene</i>	1. <i>Alliphis halleri</i>	Adult female	Phoretic

Table 1.9. Preferred sites of distribution of mite associates on the body of insect hosts and their means of attachment

Sl. No.	Species name & life stage of insect hosts	Mite species associated with insect hosts	Preferred sites of distribution of mites on the body of insect hosts	Means of attachment
1.	<i>Oxya chinensis</i> ; adult	1. <i>Leptus treati</i>	Thorax, femur	Mouthpart
	Adult	2. <i>Locustacarus chinensis</i> sp. nov.	Hindwings, abdomen	Nil
2.	<i>Oxya hyla</i> ; Adult	1. <i>Neoseiulus mapuche</i>	Hindwings	Nil
	Adult	2. <i>Leptus treati</i>	Thorax, femur	Mouthpart
	Adult	3. <i>Steneotarsonemus brasiliensis</i>	Hindwings	Nil
	Adult	4. <i>Podapolipus palappuramensis</i> sp. nov.	Hindwings, abdomen	Female adult via mouthpart
3.	<i>Odontotermes feae</i> ; Adult	1. <i>Premicrodispus paramaevi</i>	Ventral part of body	Nil
	Adult	2. <i>Rhizoglyphus vicantus</i>	Dorsal part of head	Anal sucker
	Adult	3. <i>Schweibea</i> sp.	Dorsal part of head	Anal sucker
	Adult	4. <i>Caloglyphus subterraneus</i>	Dorsal part of head	Anal sucker
4.	<i>Odontotermes obesus</i> ; Adult	1. <i>Rhizoglyphus vicantus</i>	Dorsal part of head	Anal sucker

	Adult	2. <i>Sancassania boharti</i>	Dorsal part of head	Anal sucker
	Adult	3. <i>Histiostoma herbali</i>	Dorsal part of head	Anal sucker
5.	<i>Nasutitermes gardneri</i> , Adult	1. <i>Acarus solimani</i>	Dorsal part of head	Anal sucker
	Adult	2. <i>Acotyledon tariqi</i>	Dorsal part of head	Anal sucker
	Adult	3. <i>Caloglyphus manuri</i>	Dorsal part of head	Anal sucker
	Adult	4. <i>Sapracarus</i> sp.	Dorsal part of head	Anal sucker
6.	<i>Aleurothrixus floccosus</i>	1. <i>Amblyseius largoensis</i>	*	Nil
7.	<i>Bemisia tabaci</i>	1. <i>Amblyseius channabasavanni</i>	*	Nil
		2. <i>Amblyseius largoensis</i>	*	Nil
		3. <i>Amblyseius vasiformis</i>	*	Nil
		4. <i>Euseius finlandicus</i>	*	Nil
		5. <i>Euseius ovalis</i>	*	Nil
		6. <i>Transeius kroeffis</i>	*	Nil
		7. <i>Lasioseius moolamkudensis</i> sp. nov.	*	Nil
		8. <i>Cunaxa anomala</i>	*	Nil
		9. <i>Cunaxa heterostriata</i>	*	Nil
8.	<i>Altica</i> sp.; Adult	1. <i>Histiostoma maritimus</i>	Hypomeron	Anal sucker
9.	<i>Aulacophora foveicollis</i> ; Adult	1. <i>Histiostoma sammari</i>	Hypomeron, mesoventrite, abdominal ventrite, subelytra, pronotum	Anal sucker
	Adult	2. <i>Procalvolia</i> sp.	Hypomeron	Anal sucker
10.	<i>Aulacophora frontalis</i> ; Adult	1. <i>Histiostoma sammari</i>	Hypomeron, prosternal process, mesoventrite, intercoxal process of abdominal ventrite, abdominal ventrite, hindleg and midleg femur, midleg trochanter	Anal sucker

11.	<i>Batocera rufomaculata</i> , Adult	1. <i>Uropoda orbicularis</i>	Subelytra	Anal pedicel
	Adult	2. <i>Neosilphitrombium gratum</i>	Stigmata	Mouthpart
	Adult	<i>Canestriniella batocera</i> sp. nov.	Hindwings, subelytra, abdomen	Nil
12.	<i>Cosmopolites sordidus</i> ; Adult	1. <i>Macrocheles muscaedomesticae</i>	*	Nil
	Adult	2. <i>Histiostoma furrowasp.</i> nov.	Prosternum, meso and metaventricle	Anal sucker
13.	<i>Gonocephalus</i> sp.1; Adult	1. <i>Cheyletus kuznetsovi</i>	Hypomeron	Glue like secretion
14.	<i>Gonocephalus</i> sp.2; Adult	1. <i>Hoplocheylus longispinus</i>	Dorsal part of abdomen	Nil
15.	<i>Henosepilachna vigintioctopunctata</i> ; Adult	1. <i>Histiostoma maritimus</i>	Hypomeron	Anal sucker
	Adult	2. <i>Congovidia glossinae</i>	Dorsal part of abdomen	Anal sucker
16.	<i>Hoplasoma unicolor</i> ; Adult	1. <i>Procalvolia</i> sp.	Mesoventrite	Anal sucker
17.	<i>Odoiporus longicollis</i> ; Adult	1. <i>Macrocheles muscaedomesticae</i>	*	Nil
	Adult	2. <i>Histiostoma furrowa</i> sp. nov.	Subelytra, hindwings, ventral body, anterior mesosternum	Anal sucker
18.	<i>Oryctes rhinoceros</i> ; Adult	1. <i>Schizodiplogynium rhinocera</i> sp. nov.	Mesoventrite	Nil
	Adult	2. <i>Uropoda heliocopridis</i>	Pro, meso and metacoxal base	Anal pedicel
	Larva	3. <i>Holoparasitus stramenti</i>	*	Nil
	Larva	4. <i>Digamasellus neodisetus</i>	*	Nil
	Larva	5. <i>Macrocheles perglaber</i>	*	Nil

	Adult	6. <i>Lasioseius confusus</i>	Dorsal part of abdomen	Nil
	Larva	7. <i>Laelaps</i> sp.	*	Nil
	Adult	8. <i>Hypoaspis sardous</i>	Head, prosternum, Hypomeron	Nil
	Adult	9. <i>Histiostoma sammari</i>	Hypomeron	Anal sucker
	Adult	10. <i>Athogavia oryctae</i> sp. nov.	Subelytra, hindwings, abdomen	Nil
	Egg	11. <i>Acotyledon tariqi</i>	*	Anal sucker
	Adult	12. <i>Sancassania boharti</i>	Hypomeron	Anal sucker
	Egg, adult	13. <i>Tyrophagus putrescentiae</i>	Hindwings	Nil
19.	<i>Rhynchophorus ferrugineus</i> ; Adult	1. <i>Tridiplogynium rhynchophora</i> sp. nov.	Abdominal ventrite	Nil
	Adult	2. <i>Centrouropoda almerodai</i>	Subelytra	Anal pedicel
	Adult	3. <i>Uroobovella assamomarginata</i>	Meso and meta-ventrite	Anal pedicel
	Adult	4. <i>Uroobovella javae</i>	Antenna, coxal base	Anal pedicel
	Adult	5. <i>Uroobovella phoenicicola</i>	Coxal base	Anal pedicel
	Adult	6. <i>Digamasellus quadrisetus</i>	Subelytra	Nil
	Larva	7. <i>Macrocheles krantzi</i>	*	Nil
	Larva	8. <i>Macrocheles perglaber</i>	*	Nil
	Adult	9. <i>Dinogamasus</i> sp.	Prosternum	Nil
	Adult	10. <i>Curculanoetus keralensis</i> sp. nov.	Subelytra	Anal sucker
20.	<i>Xystocera globosa</i> ; Adult	1. <i>Uropoda shangaica</i>	Dorsal part of abdomen	Anal pedicel
21.	<i>Onitis philemon</i> ; Adult	1. <i>Uroobovella pilosetosa</i>	Coxal base	Anal pedicel
		2. <i>Macrocheles glaber</i>	*	Nil
		3. <i>Hoplocheylus zanzibarensis</i>	Dorsal part of abdomen	Nil
22.	<i>Copris repertus</i> ; Adult	1. <i>Holoparasitus stramenti</i>	*	Nil
		2. <i>Poechilochirus</i> sp.	*	Nil
		3. <i>Macrocheles krantzi</i>	*	Nil
		4. <i>Hypoaspis subterranea</i>	Prosternum	Nil

		5. <i>Pygmephorellus indicus</i> sp. nov.	Dorsal part of abdomen	Nil
23.	<i>Catharsius molossus</i> ; Adult	1. <i>Alliphis</i> sp.	*	Nil
		2. <i>Hypoaspis heselhousi</i>	Prosternum	Nil
		3. <i>Pavania foliata</i>	Dorsal part of abdomen	Nil
24.	<i>Melanitis leda ismene</i> ; Adult	1. <i>Alliphis halleri</i>	Under proboscis	Nil

*No preference for any particular body part of the insect host

Table 1.10. Mite species which exhibit multiple distribution sites on the host body

Mite species	Body Parts	No. of Mites	Percentage	Range
1. <i>Hypoaspis sardous</i> on <i>Oryctes rhinoceros</i>	Head	74±2*	28.91%	0-15
	Prosternum	164±1.32*	64.06%	0-24
	Hypomeron	18±1.11*	7.03%	0-7
2. <i>Athogavia oryctae</i> sp. nov. on <i>Oryctes rhinoceros</i>	Hindwings	163±2.01*	29.96%	0-30
	Subelytra	87±0.25*	15.99%	0-39
	Abdomen	294±3.15*	54.04%	0-113
3. <i>Uropoda heliocopridis</i> on <i>Oryctes rhinoceros</i>	Procoxal base	138±6.44*	57.02%	0-24
	Mesocoxal base	31±0.11*	12.81%	0-14
	Metacoxal base	73±0.22*	30.17%	0-29
4. <i>Uroobovella javae</i> on <i>Rhynchophorus ferrugineus</i>	Antenna	162±0.54*	20.15%	6-15
	Coxal base	642±2.02*	79.85%	31-46
5. <i>Uroobovella assamomarginata</i> on <i>Rhynchophorus ferrugineus</i>	Mesoventrite	132±3.02*	71.35%	7-12
	Metaventrite	53±2.75*	28.65%	1-6
6. <i>Canestriniella batocera</i> sp. nov. on <i>Batocera rufomaculata</i>	Hindwings	637±2.33*	49.69%	74-110
	Subelytra	499±6.45*	38.92%	58-81
	Abdomen	146±5.98*	11.39%	6-35
7. <i>Histiostoma sammari</i> on <i>Aulacophora foveicollis</i>	Hypomeron	2259±3.44*	85.02%	0-47

	Abdominal ventrite	61±0.28*	2.30%	0-23
	Sub elytra	56±1.45*	2.11%	0-18
	Mesoventrite	264±6.32*	9.94%	0-31
	Pronotum	17±1.03*	0.64%	0-5
8. <i>Histiostoma sammari</i> on <i>Aulacophora frontalis</i>	Prosternal process	73±0.26*	22.19%	0-7
	Mesoventrite	180±4.25*	54.71%	0-22
	Intercostal process of abdominal ventrite	65±1.54*	19.76%	0-10
	Abdominal Ventrite	5±0.21*	1.52%	0-3
	Hindleg femur	4±0.32*	1.22%	0-4
	Midleg femur	1±0.04*	0.30%	0-1
	Midleg trochanter	1±0.25*	0.30%	0-1
9. <i>Histiostoma furrowa</i> sp. nov. on <i>Odoiporus longicollis</i>	Prosternum	255±4.02*	12.6%	0-36
	Meso-ventrite	208±3.22*	10.38%	0-35
	Meta-ventrite	56±0.24*	2.76%	0-29
	Abdominal ventrite	11±0.08*	0.54%	0-4
	Sub elytral surface	505±4.53*	25.23%	0-317
	Hind wings	52±0.64*	2.59%	0-96
	Elytra	12±0.13*	0.59%	0-10
	Groove anterior to mesosternum	905±4.22*	45.34%	0-114
10. <i>Histiostoma furrowa</i> sp. nov. on <i>Cosmopolites sordidus</i>	Prosternum	19±2.10*	48.32%	0-11
	Mesoventrite	9±0.15*	23.07%	0-6
	Metaventrite	11±1.15*	28.2%	0-9
11. <i>Leptus treati</i> on <i>Oxya chinensis</i>	Thorax	7±0.54*	70%	0-2
	Femur	3±0.11*	30%	0-1
12. <i>Locustacarus chinensis</i> sp. nov.	Hindwings	17±0.23*	40.4%	0-5
	Abdomen	25±1.12*	59.5%	0-11

13. <i>Leptus treati</i> on <i>Oxya hyla</i>	Thorax	9±0.23*	69.2%	0-2
	Femur	4±0.14*	30.7%	0-1
14. <i>Podapolipus palappuramensis</i> sp.nov. on <i>Oxya hyla</i>	Hindwings	43±2.33*	31.32%	0-17
	Abdomen	94±3.14*	68.61%	0-46

* Statistically significant using Mann Whitney U Test with $p < 0.05$ ($p = 0.040$)

Table 1.11. Various parameters regarding mite infestation on different species of insect hosts

Name of insect	Total number of insects collected	Percentage of occurrence of mites	Mite species	Prevalence	Mean intensity	Range
<i>Oxya chinensis</i>	53	64%	<i>Leptus treati</i>	62%	1.51±0.5	1–2
			<i>Locustacarus chinensis</i> sp. nov.	28%	8.78±2.32	5–12
<i>Oxya hyla</i>	40	70%	<i>Leptus treati</i>	60%	1.72±0.7	1–3
			<i>Podapolipus palappuramensis</i> sp. nov.	65%	36.72±10.24	16–53
			<i>Neoseiulus mapuche</i>	0.05%	1±0	1
			<i>Steneotarsonemus brasiliensis</i>	0.075%	1.33±0.57	1–3
<i>Odontotermes feae</i>	34	68%	<i>Premicrodispus paramaevi</i>	0.14%	2.4±0.89	1–3
			<i>Rhizoglyphus vicantus</i>	38.2%	1.53±0.51	1–2
			<i>Schweibea</i> sp.	8.8%	1±0	1
			<i>Caloglyphus subterraneousi</i>	26.4%	1.77±0.83	1–3
<i>Odontotermes obesus</i>	50	57%	<i>Rhizoglyphus vicantus</i>	28%	1.21±0.42	1–2
			<i>Sancassania boharti</i>	24%	1.75±0.86	1–3

			<i>Histiostoma herbali</i>	8.8%	1±0	1–3
<i>Nasutitermes gardneri</i>	45	53%	<i>Acarus solimani</i>	35%	1.62±0.8	1–3
			<i>Acotyledon tariqi</i>	8.8%	1±0	1
			<i>Caloglyphus manuri</i>	13.33%	1.33±0.51	1–2
			<i>Sapracarus</i> sp.	6.6%	1.66±0.57	1–2
<i>Altica</i> sp	52	7.7%	<i>Histiostoma maritimus</i>	7.69%	2.5±1.29	1–4
<i>Aulacophora foveicollis</i>	203	86.2%	<i>Histiostoma sammari</i>	84.24%	55.46±24.16	12–88
			<i>Procalvolia</i> sp.	8.69%	9.7±4.63	1–16
<i>Aulacophora frontalis</i>	53	83.01%	<i>Histiostoma sammari</i>	83.01%	17.5±7.24	7–29
<i>Batocera rufomaculata</i>	8	87.5%	<i>Uropoda orbicularis</i>	25%	18±4.24	15–21
			<i>Neosilphitrombium gratum</i>	12.5%	35±0	35
			<i>Canestriniella batocera</i> sp. nov.	87.5%	214±42.24	160–312
<i>Cosmopolites sordidus</i>	37	34%	<i>Macrocheles muscaedomesticae</i>	5.4%	1±0	1
			<i>Histiostoma furrowa</i> sp.nov.	32.4%	12.51±4.19	5–18
<i>Gonocephalus</i> sp.1	15	80%	<i>Cheyletus kuznetsovi</i>	80%	8.25±2.83	4–12
<i>Gonocephalus</i> sp.2	5	20%	<i>Hoplocheylus longispinus</i>	20%	83±0	83
<i>Henosepilachna vigintioctopunctata</i>	40	35%	<i>Histiostoma maritimus</i>	35%	4.57±1.69	2–8
			<i>Congovidia glossinae</i>	5%	1.5±0.7	1–2
<i>Hoplasoma unicolor</i>	66	87.9%	<i>Procalvolia</i> sp.	87.9%	8.9±2.95	5–14
<i>Odoiporus longicollis</i>	256	91.8%	<i>Macrocheles muscaedomesticae</i>	4%	1.25±0.46	1–2
			<i>Histiostoma furrowa</i> sp. nov.	91.79%	30.26±2.39	
<i>Oryctes rhinoceros</i> Adult	50	82%	<i>Schizodiplogynium rhinocera</i> sp.nov.	50%	22.04±7.58	8–32
			<i>Uropoda heliocopridis</i>	22%	40±3.40	35–43

			<i>Lasioseius confusus</i>	24%	28.33±2.60	24–32
			<i>Hypoaspis sardous</i>	54%	23.1±5.60	17–31
			<i>Histiostoma sammari</i>	6%	7.66±2.3	5–9
			<i>Athogavia oryctae</i> sp. nov.	54%	117±3.61	110–122
			<i>Sancassania boharti</i>	8%	15.75±0.95	15–17
			<i>Tyrophagus putrescentiae</i>	2%	7±0	7
<i>Oryctes rhinoceros</i> Larva	25	77.2%	<i>Holoparasitus stramenti</i>	8%	2.5±0.7	2–3
			<i>Digamasellus neodisetus</i>	20%	2±0.7	1–3
			<i>Macrocheles perglaber</i>	16%	2.75±0.95	2–4
			<i>Laelaps</i> sp.	8%	1.5±0.7	1–2
<i>Oryctes rhinoceros</i> Egg	7	100%	<i>Acotyledon tariqi</i>	100%	2.85±0.89	2–4
			<i>Tyrophagus putrescentiae</i>	100%	4±1	3–5
<i>Rhynchophorus ferrugineus</i> Adult	22	86.3%	<i>Tridiplogynium rhynchophora</i> sp. nov.	9%	1.5±0.7	1–2
			<i>Centrouropoda almerodai</i>	81.8%	51.6±10.97	35–66
			<i>Uroobovella assamomarginata</i>	63.6%	13.21±1.25	12–15
			<i>Uroobovella javae</i>	72.7%	51±2.92	47–55
			<i>Uroobovella phoenicicola</i>	22.7%	6±1	5–7
			<i>Digamasellus quadrisetus</i>	13.63%	20±2	18–22
			<i>Dinogamasus</i> sp.	4.54%	2	2
			<i>Curculanoetus keralensis</i> sp. nov.	86.3%	84.21±5.94	75–93
<i>Rhynchophorus ferrugineus</i> Larva	8	37.5%	<i>Macrocheles krantzi</i>	25%	1.5±0.7	1–2
			<i>Macrocheles perglaber</i>	12.5%	2	2
<i>Xystocera globosa</i>	5	40%	<i>Uropoda shangaica</i>	40%	71±8.48	65–77
<i>Onitis philemon</i>	10	70%	<i>Uroobovella pilosetosa</i>	20%	4±1.4	3–5

			<i>Macrocheles glaber</i>	40%	2.75±0.95	2–4
			<i>Hoplocheylus zanzibarensis</i>	30%	54.33±8.14	45–60
<i>Copris repertus</i>	14	57.1%	<i>Holoparasitus stramenti</i>	7.1%	2	2
			<i>Poechilocheilus</i> sp.	7.1%	3	3
			<i>Macrocheles krantzi</i>	42.8%	2.33±0.51	2–3
			<i>Hypoaspis subterranea</i>	14.2%	3±1.4	2–4
			<i>Pygmephorus indicus</i> sp. nov.	14.2%	104±15.5	93–115
<i>Catharsius molossus</i>	7	71.4%	<i>Alliphis</i> sp.	14.2%	1	1
			<i>Hypoaspis heselhousei</i>	57.1%	1.25±0.5	1–2
			<i>Pavania foliata</i>	28.5%	134±28.2	114–154
<i>Melanitis leda ismene</i>	8	25%	<i>Alliphis halleri</i>	25%	4±1.4	3–5

Table 1.12. Details of mites associated with whitefly infested leaves

Insect species	Total number of leaves collected	Host plant	Mite species	Prevalence	Mean intensity	Range
<i>Aleurothrixus floccosus</i>	15	Guava	<i>Amblyseius largoensis</i>	26.6%	1.5±0.57	1–2
<i>Bemisia tabaci</i>	63	Chilli	<i>Lasioseius moolamkudensis</i> sp. nov.	58.7%	2.7±1.26	1–5
			<i>Amblyseius largoensis</i>	25.3%	2.1±0.75	1–3
			<i>Amblyseius vasiformis</i>	6.3%	1.25±0.25	1–2
			<i>Amblyseius channabasa vannai</i>	7.1%	2.3±0.42	1–3
			<i>Cunaxa anomali</i>	3%	1±0	1
			<i>Cunaxa heterostriata</i>	1.5%	1±0	1
			<i>Transeius kroeffis</i>	7.9%	1.4±0.5	1–2
			<i>Euseius ovalis</i>	19%	1.6±0.8	1–3
<i>Bemisia tabaci</i>	10	Spinach	<i>Euseius ovalis</i>	20%	1.5±0.7	1–2
<i>Bemisia tabaci</i>	10	Brinjal	<i>Euseius finlandicus</i>	30%	1±0	1

Table 1.13. Body weight variations of selected species of insect hosts due to phoretic mite load

Name of insect	Mean body weight of insect host with phoretic load of mites (in mg)	Mean body weight of insect host without phoretic mite load (in mg)
<i>Odoiporus longicollis</i>	125.27± 3.99*	121.35 ± 4.02*
<i>Oryctes rhinoceros</i>	1829.8±19.21*	1807.40±19.57*
<i>Rhynchophorus ferrugineus</i>	1017.70±29.21*	974.30±27.48*

*Statistically significant as per Wilcoxon Signed Ranks Test with $p < 0.05$

Table 1.14. Mean duration of development and life stages of *Histiostoma furrowa* sp. nov. (in hours) (for ten observations)

Egg-larva	Larva	Larva quiescence	Protonymph	Protoquiescence	Deutonymph	Deutoquiescence	Tritonymph	Tritoquiescence
42.3 ±0.67	24.2 ±0.32	9.8±0.78	24.3±0.27	6.5±0.23	31±4.7 (on weevil carcass) 133.73±7.74 (on pseudoscorpion and yeast solution)	7.3±0.2	23.2±0.27	6.7±0.24

Table 1.15. Mean duration of pre-oviposition, oviposition, post-oviposition and eggs laid/female of *Histiostoma furrowa* sp. nov. (in hours) (for ten observations)

Pre-oviposition	Oviposition	Post-oviposition	Eggs/female
28.6±0.7	47±1.45	72.7±1.24	15.2±1.87

Histiostoma furrowa sp. nov

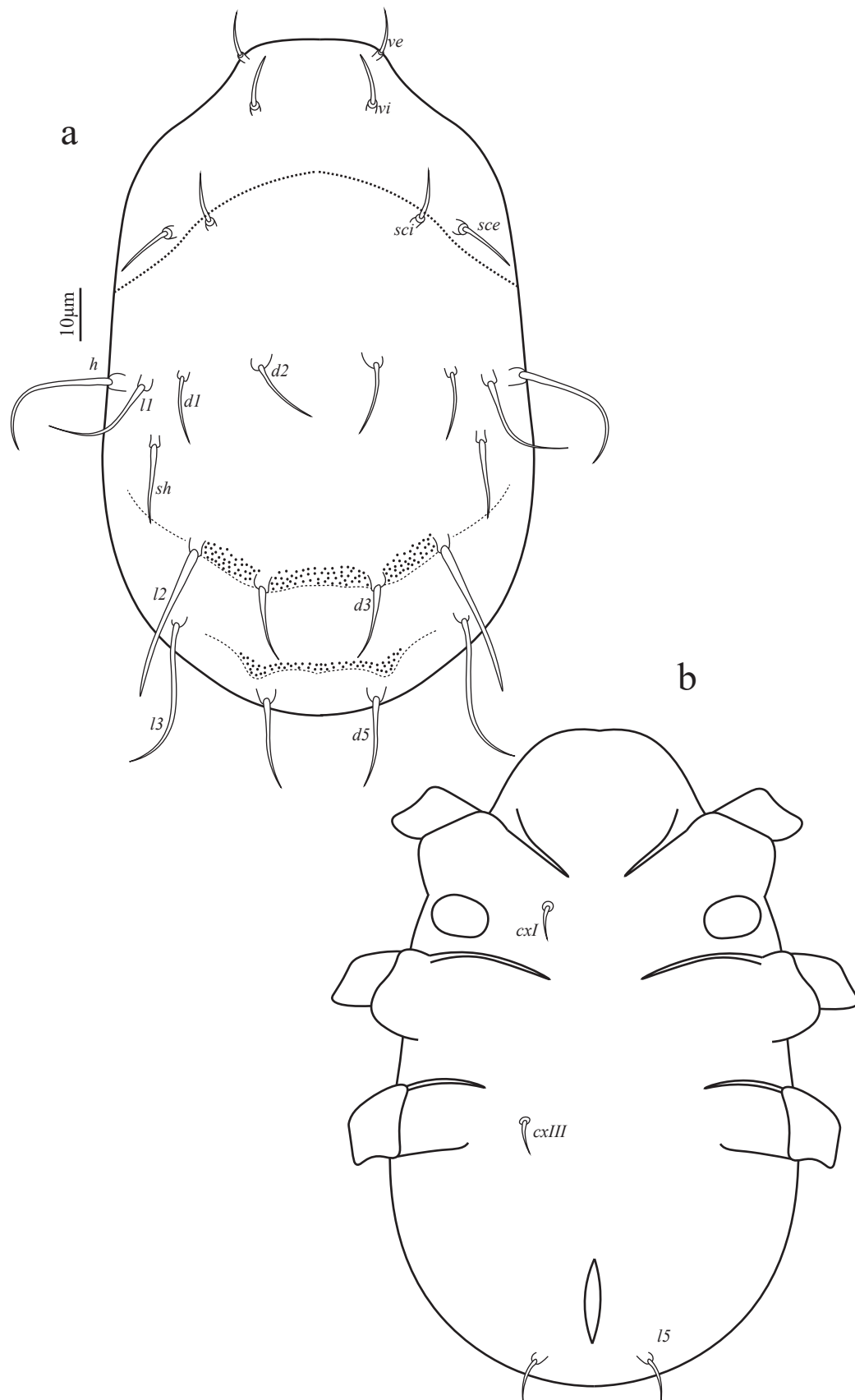


Fig. 1.42. *Histiostoma furrowa* sp. nov. Larva. a. Dorsum, b.Venter

Histiostoma furrowa sp. nov

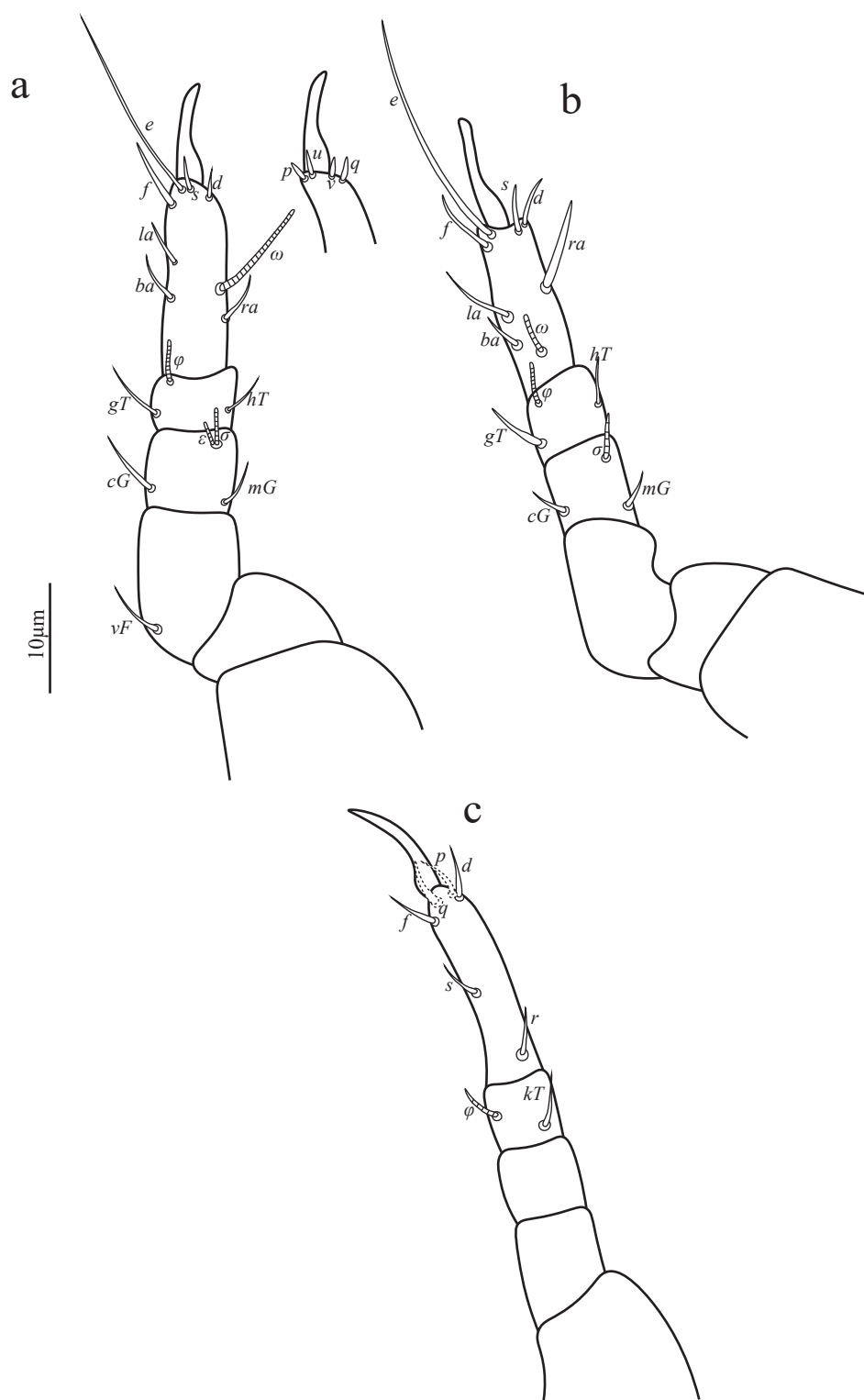


Fig.1.43. *Histiostoma furrowa* sp. nov. Larva. a.Leg I, b.Leg II, c.Leg III.

Histiostoma furrowa sp. nov.



Fig. 1.44. *Histiostoma furrowa* sp. nov. Protonymph. a.Dorsum, b.Venter

Histiostoma furrowa sp. nov.

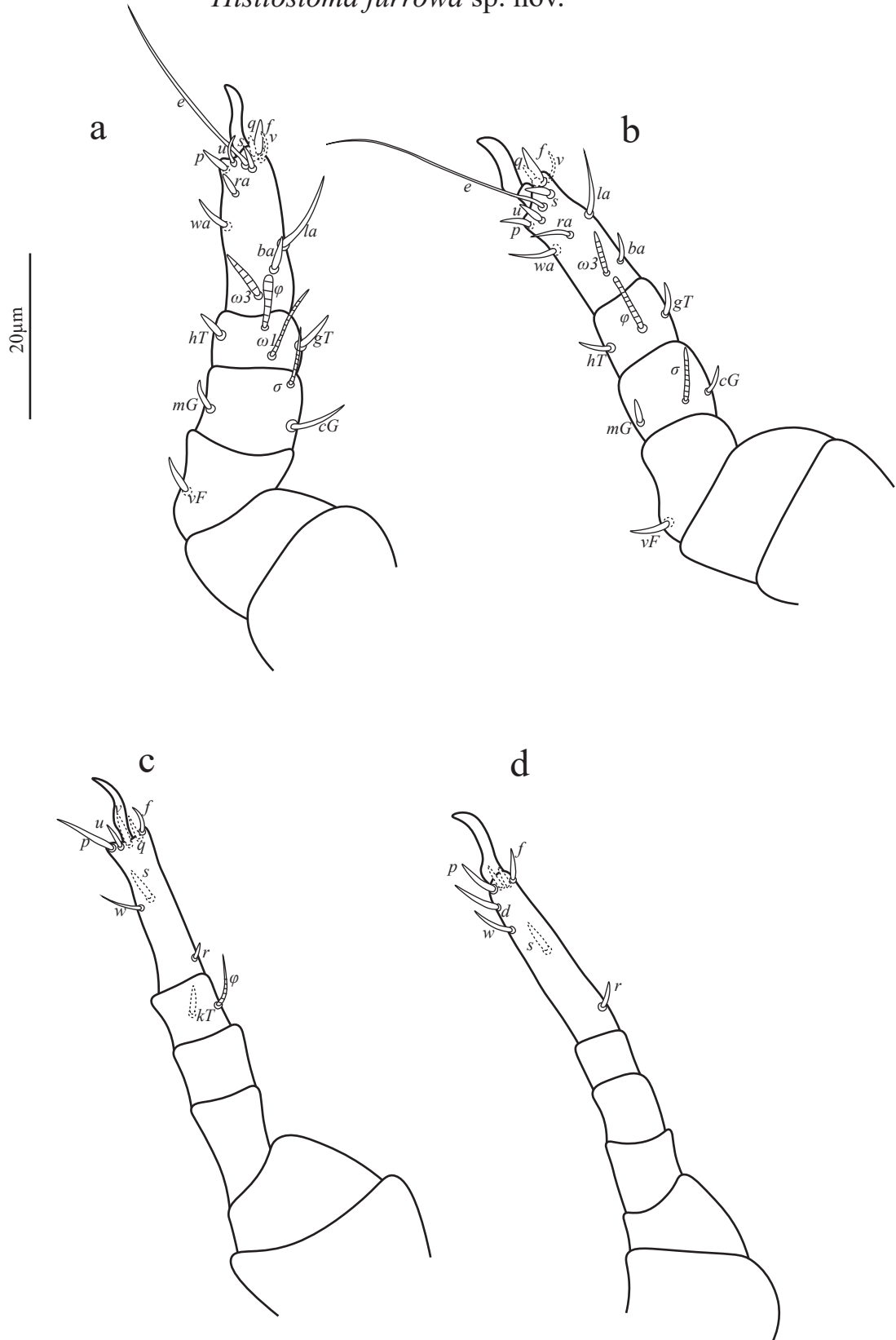


Fig. 1.45. *Histiostoma furrowa* sp. nov. Protonymph. a.Leg I, b.Leg II, c.Leg III, d.Leg IV.

Histiostoma furrowa sp. nov.

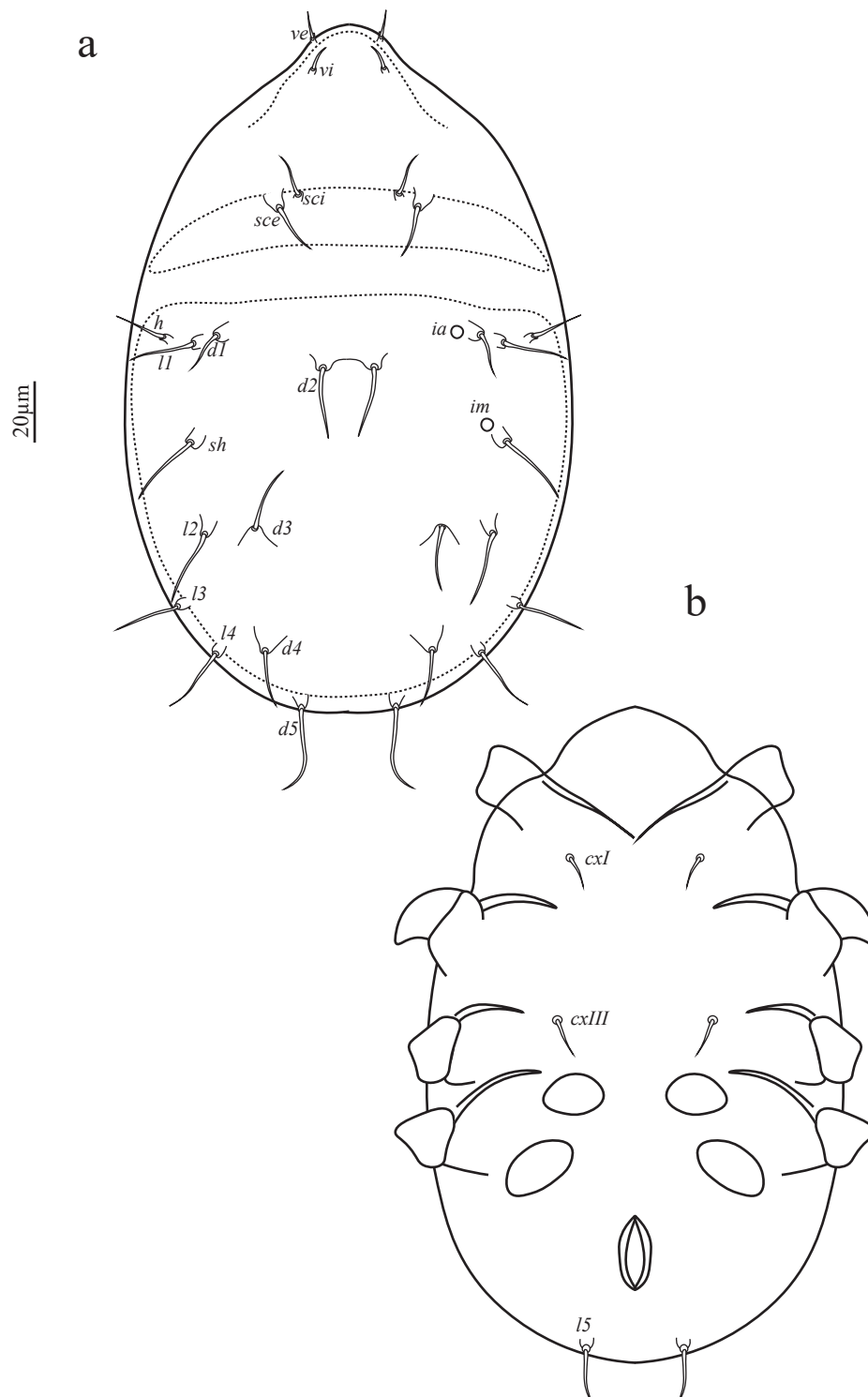


Fig. 1.46. *Histiostoma furrowa* sp. nov. Tritonymph. a.Dorsum, b.Venter

Histiostoma furrowa sp. nov.

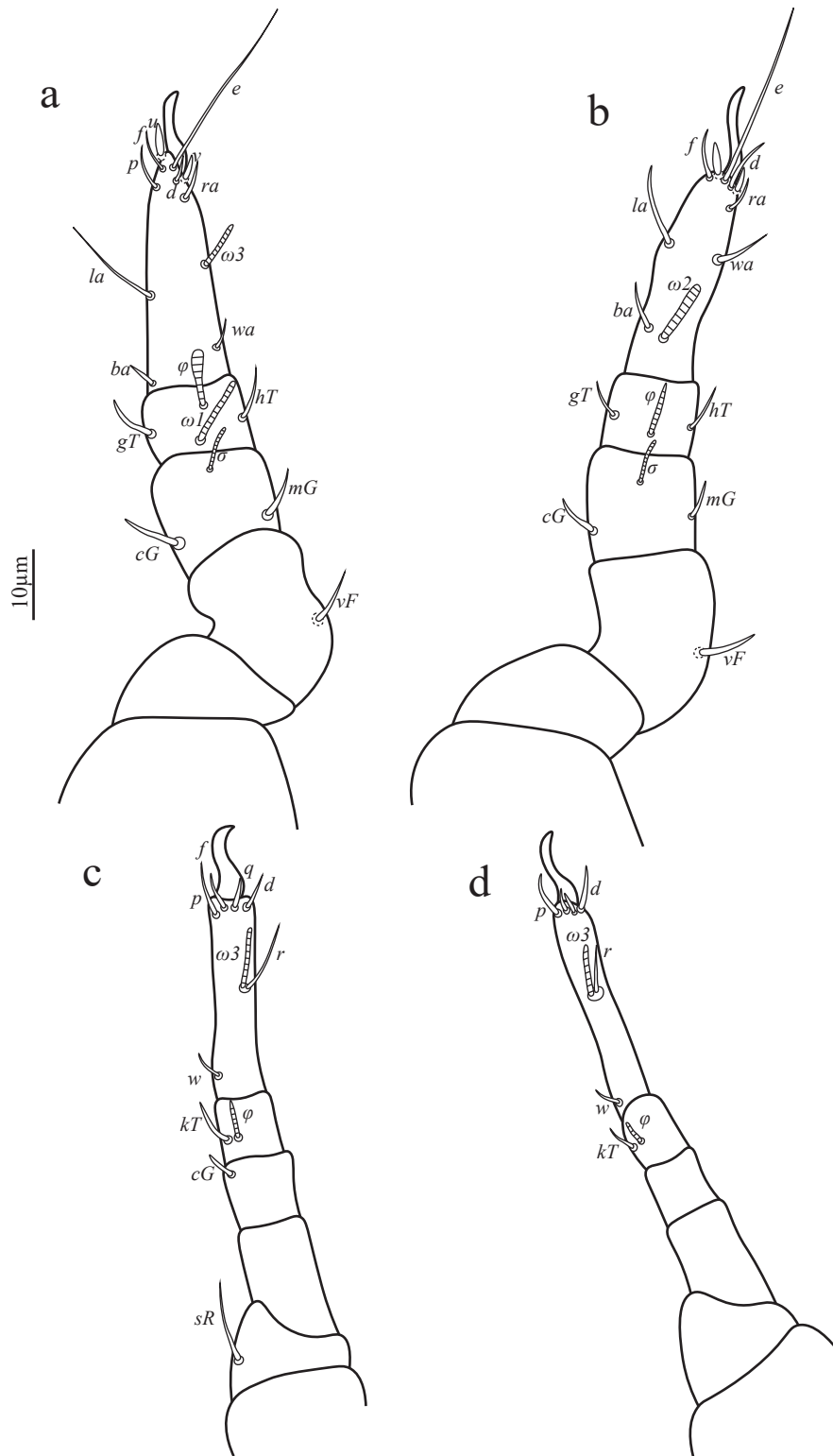


Fig. 1.47. *Histiostoma furrowa* sp. nov. Tritonymph. a. Leg I, b. Leg II, c. Leg III, d. Leg IV

Histiostoma furrowa sp.nov.

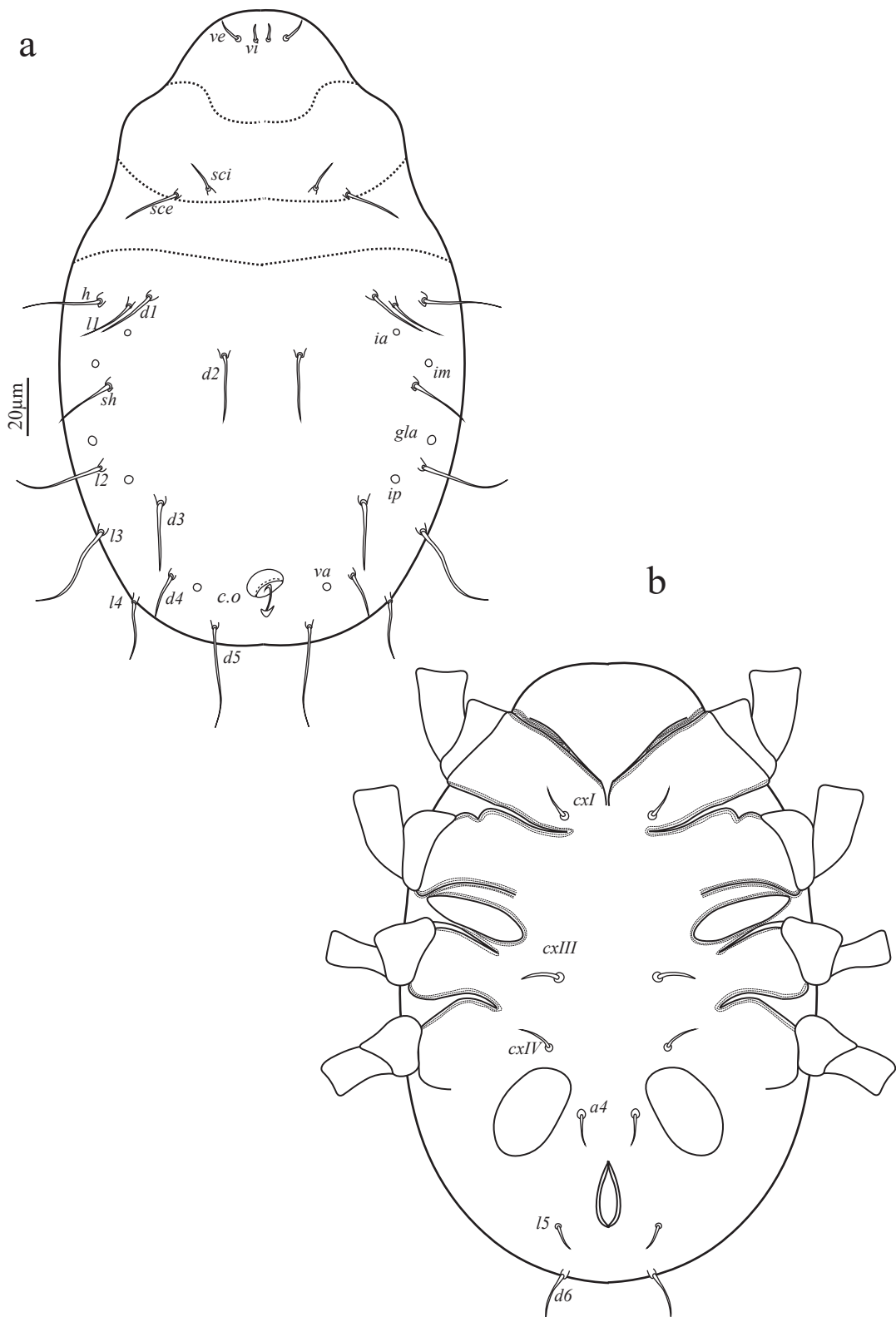


Fig. 1.48. *Histiostoma furrowa* sp.nov. Adult female a.Dorsum, b.Venter

Histiostoma furrowa sp. nov.

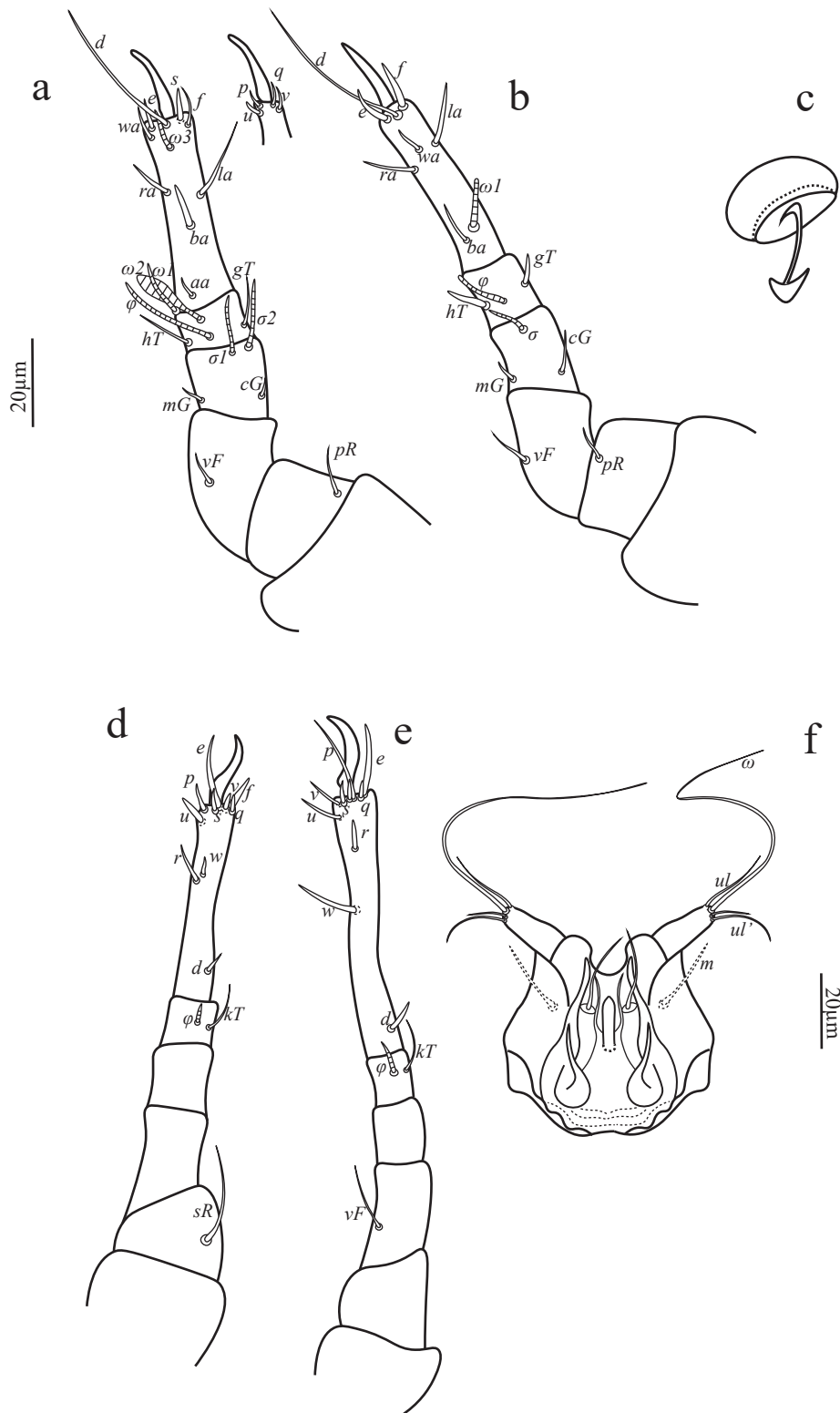


Fig. 1.49. *Histiostoma furrowa* sp. nov. Adult female. a. Leg I, b. Leg II, c. Bursa copulatrix, d. Leg III, e. Leg IV, f. Gnathosoma.

Histiostoma furrowa sp. nov.

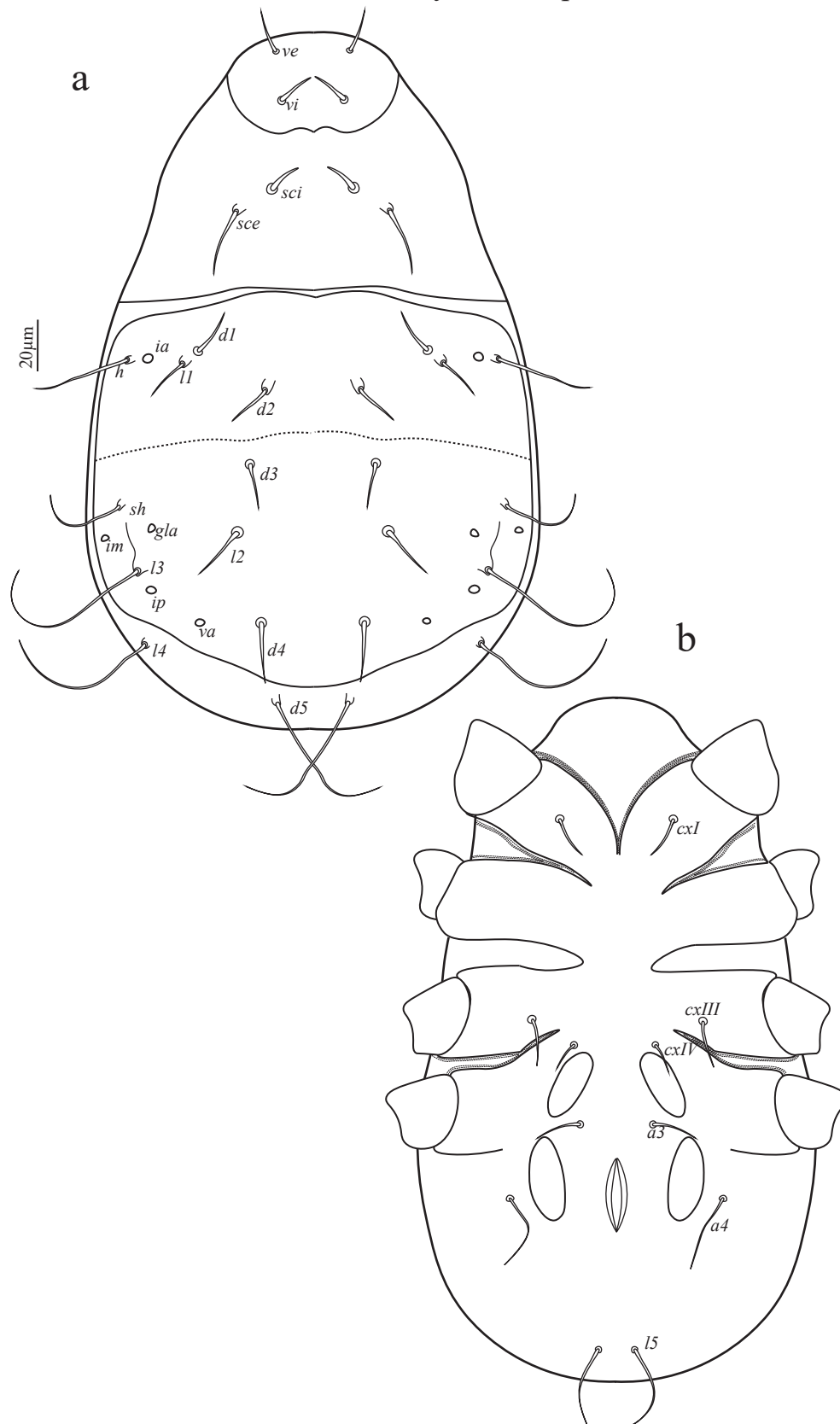


Fig. 1.50. *Histiostoma furrowa* sp.nov. Adult male. a.Dorsum, b.Venter.

Histiostoma furrowa sp. nov.

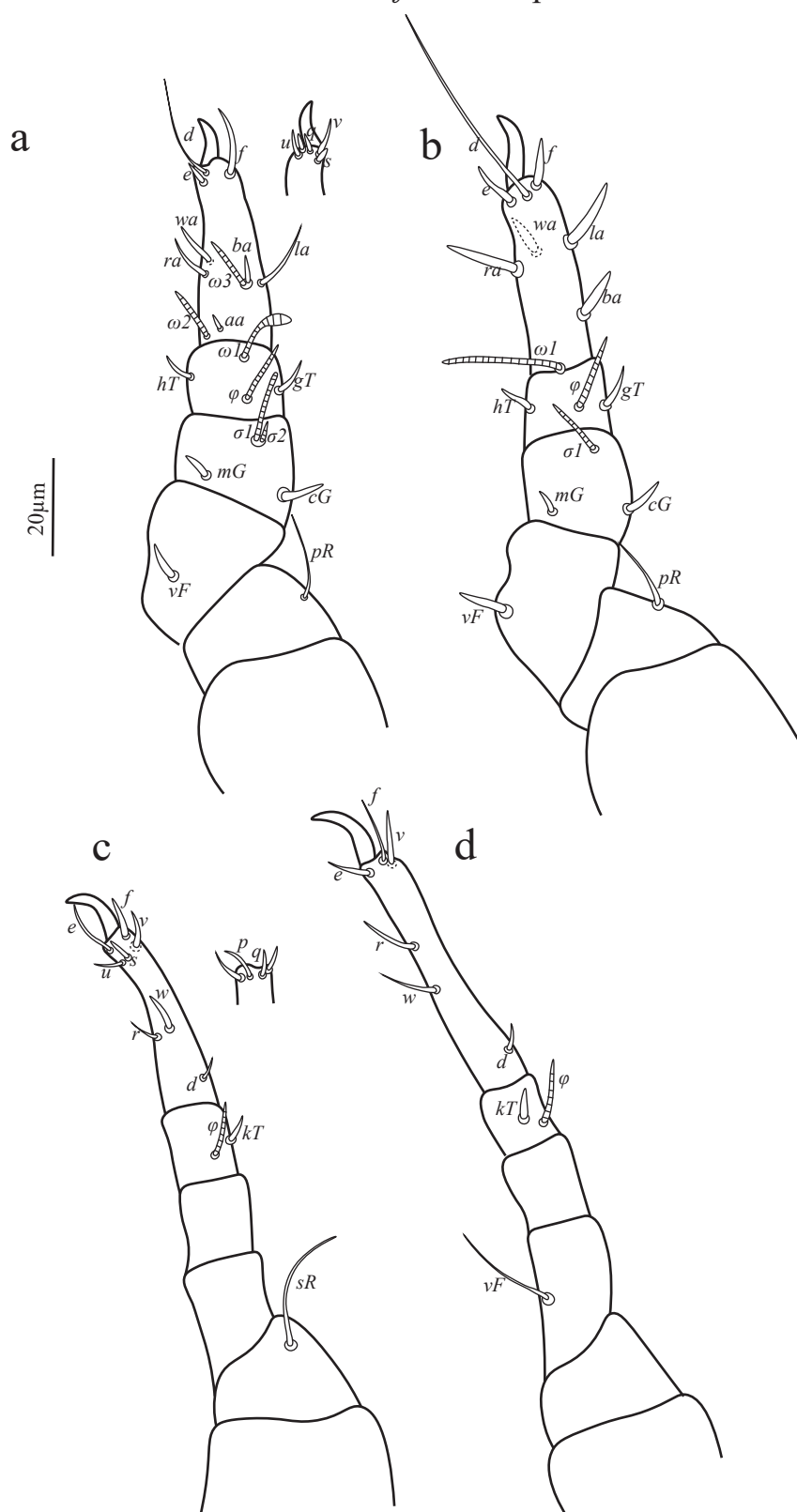


Fig. 1.51. *Histiostoma furrowa* sp. nov. Adult male a. Leg I, b. Leg II, c. Leg III, d. Leg IV.

Tridiplogynium rhynchophora sp. nov.

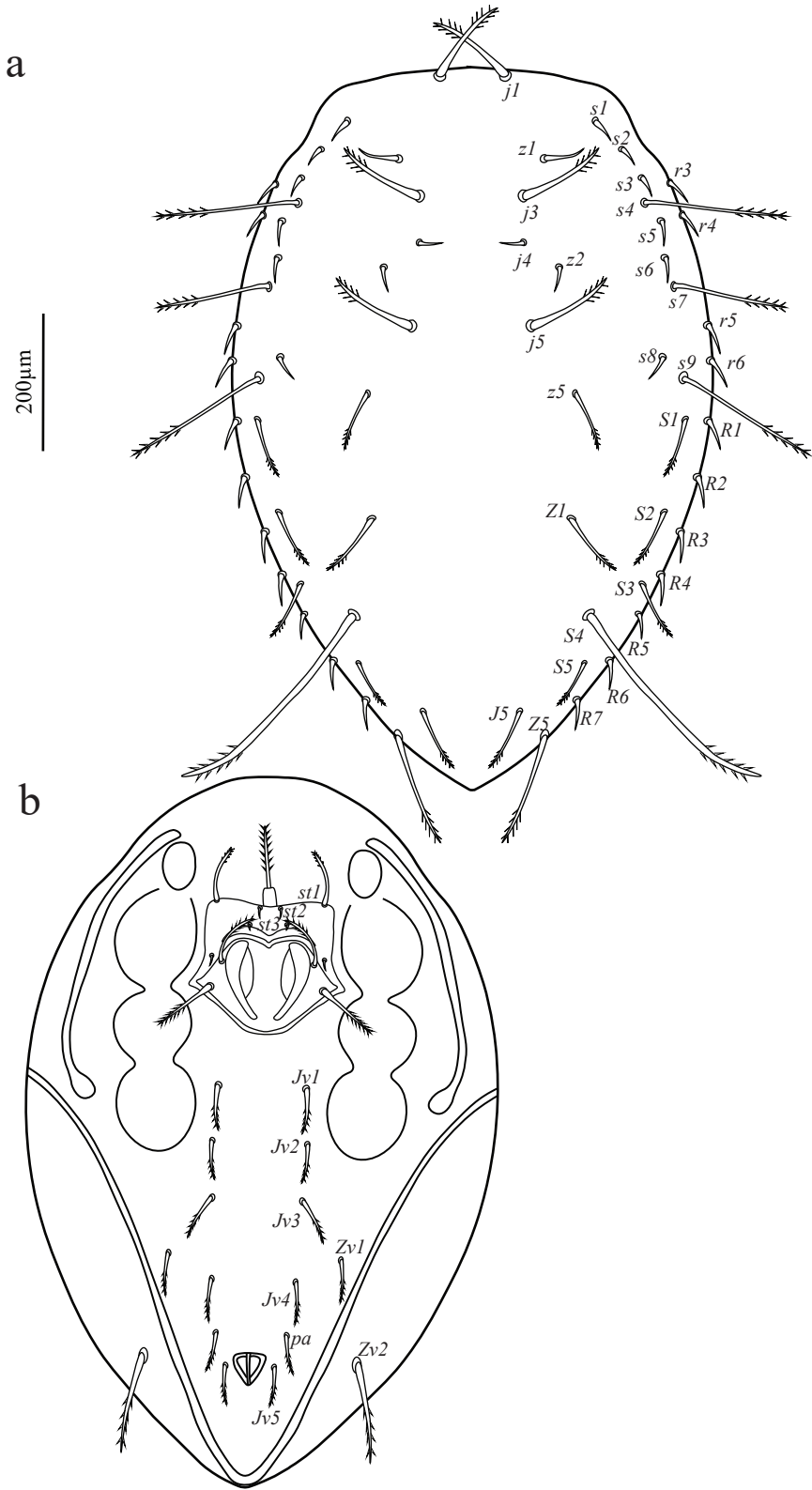


Fig. 1.52. *Tridiplogynium rhynchophora* sp. nov. a.Dorsum, b.Venter. Scale 200 μ m

Tridiplogynium rhynchophora sp. nov.

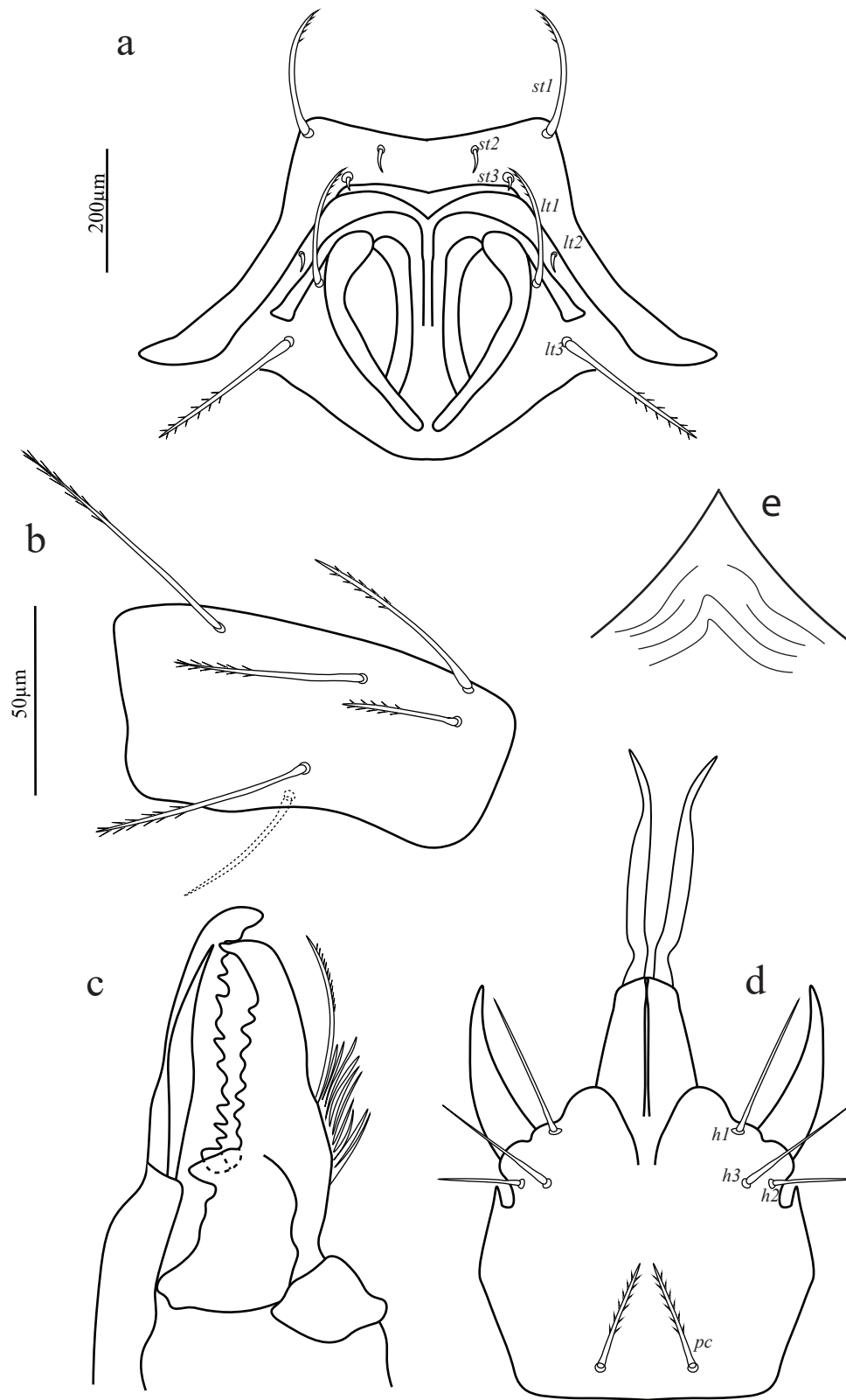


Fig. 1.53. *Tridiplogynium rhynchophora* sp. nov. a. Sternitigenital shield, b. Genu IV, c. Chelicera, d. Subcapitulum, e. Gnathotectum.

Schizodiplogynium rhinocera sp. nov.

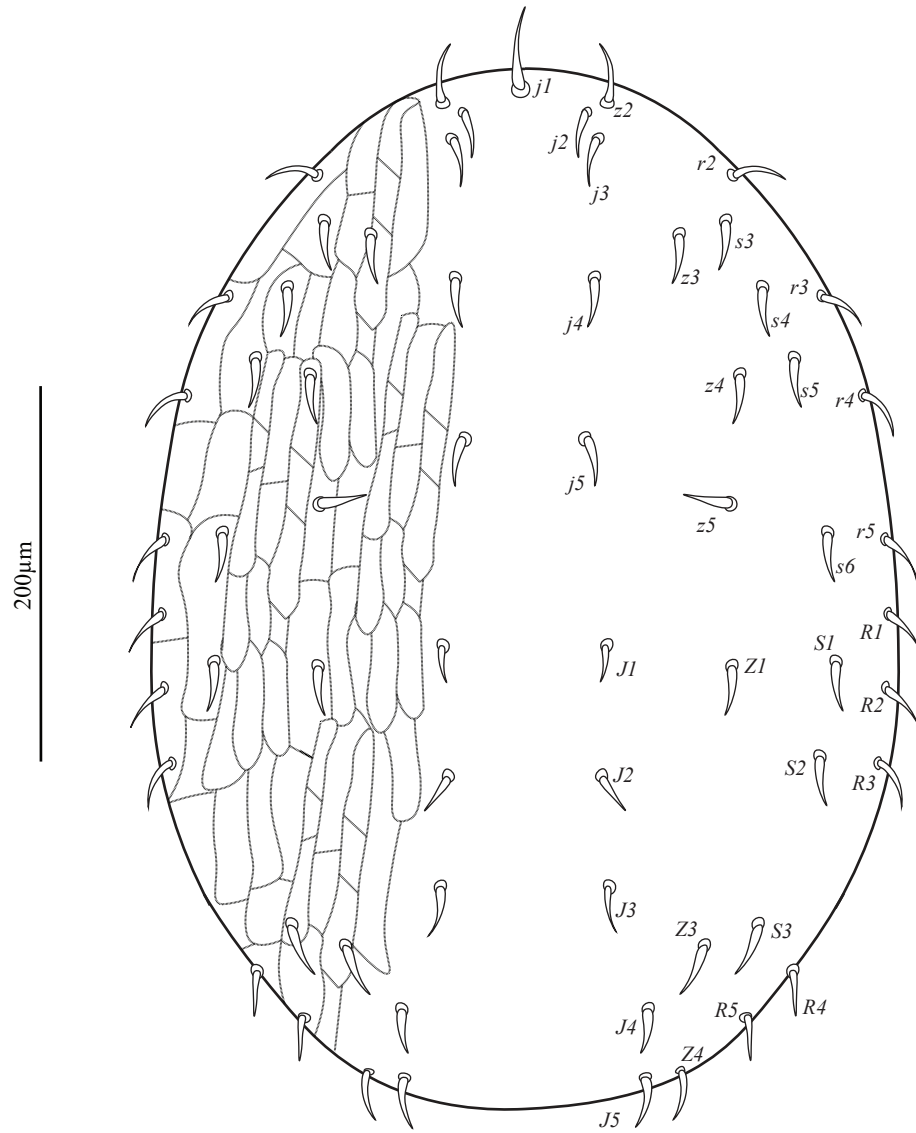


Fig. 1.54. *Schizodiplogynium rhinocera* sp. nov. Dorsum

Schizodiplogynium rhinocera sp. nov.

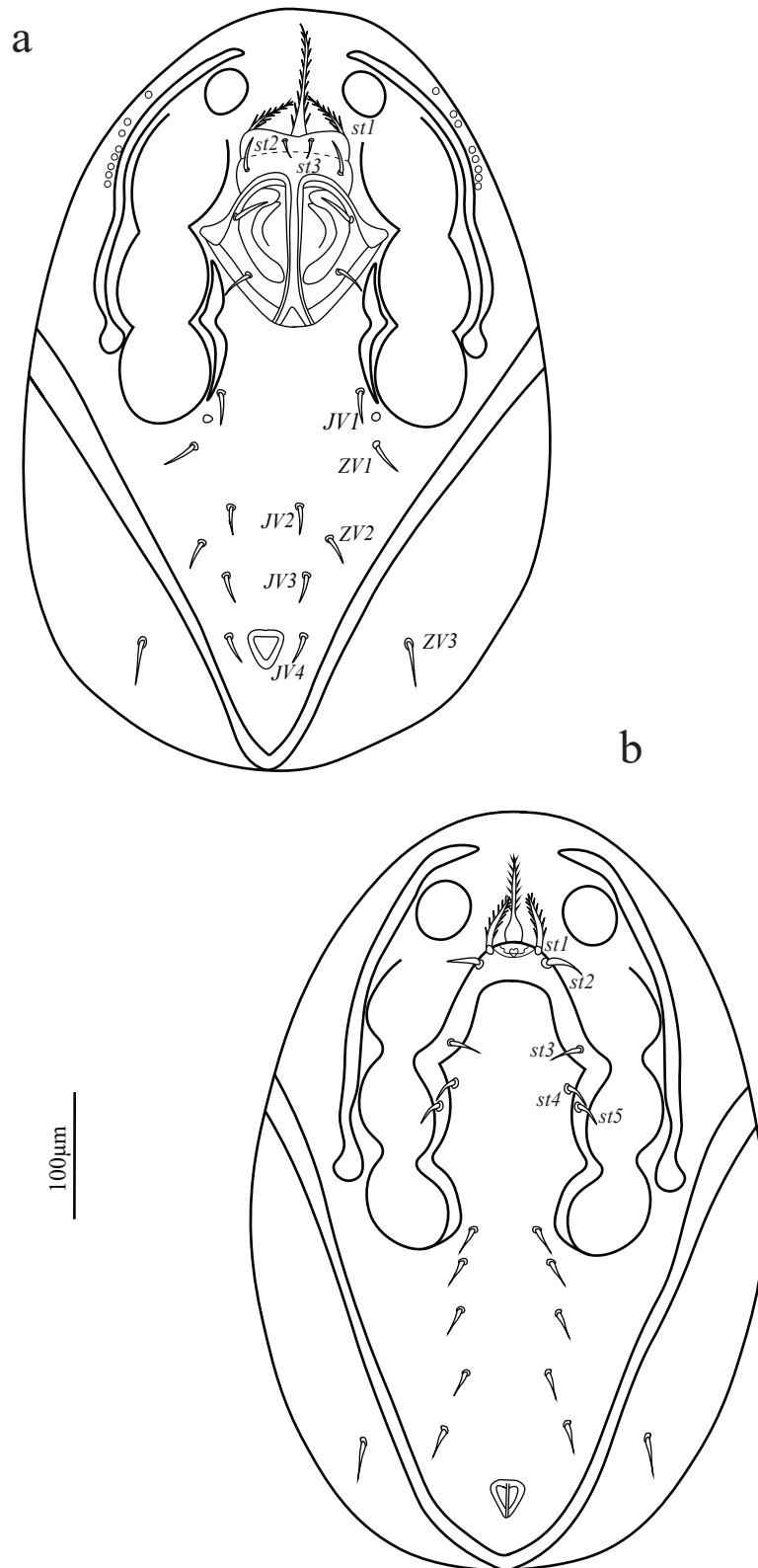
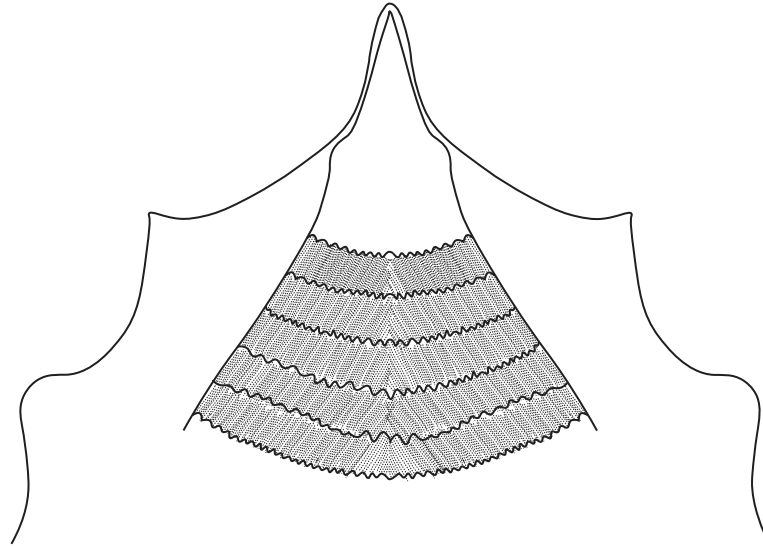


Fig. 1.55. *Schizodiplogynium rhinocera* sp. nov. a.Venter of female, b.Venter of male.

Schizodiplogynium rhinocera sp. nov.

a



50µm

b

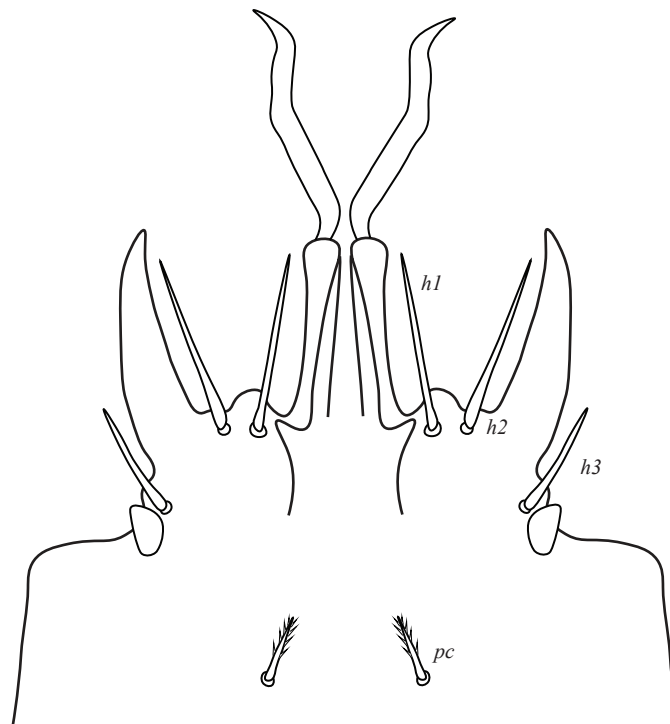


Fig. 1.56. *Schizodiplogynium rhinocera* sp. nov. a. Gnathotectum, b. Subcapitulum

Schizodiplogynium rhinocera sp. nov.

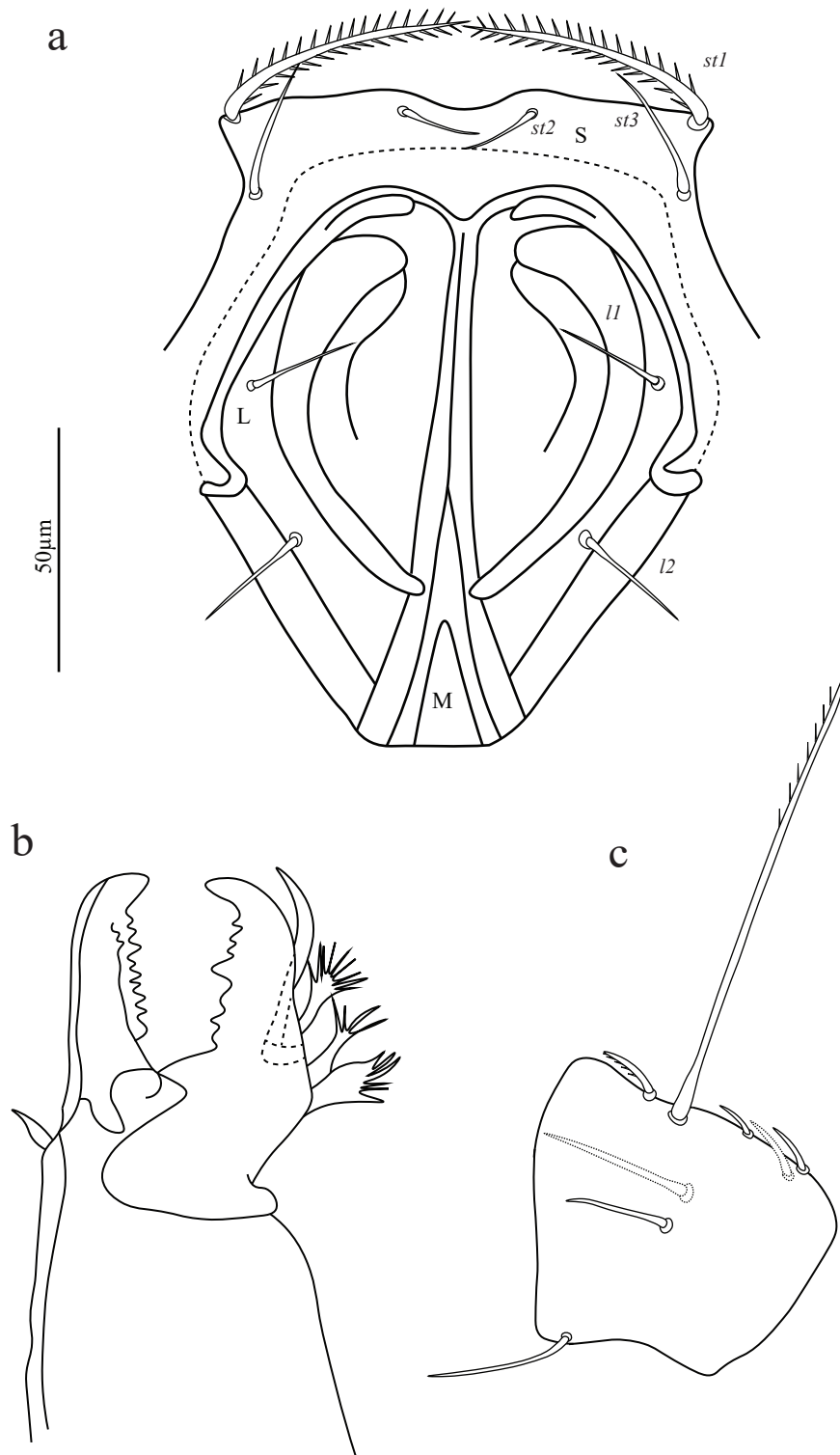


Fig. 1.57. *Schizodiplogynium rhinocera* sp. nov. a. Sternitigenital shield, b. Chelicera, c. Genu IV.

Uropoda heliocopridis Oudemans, 1901

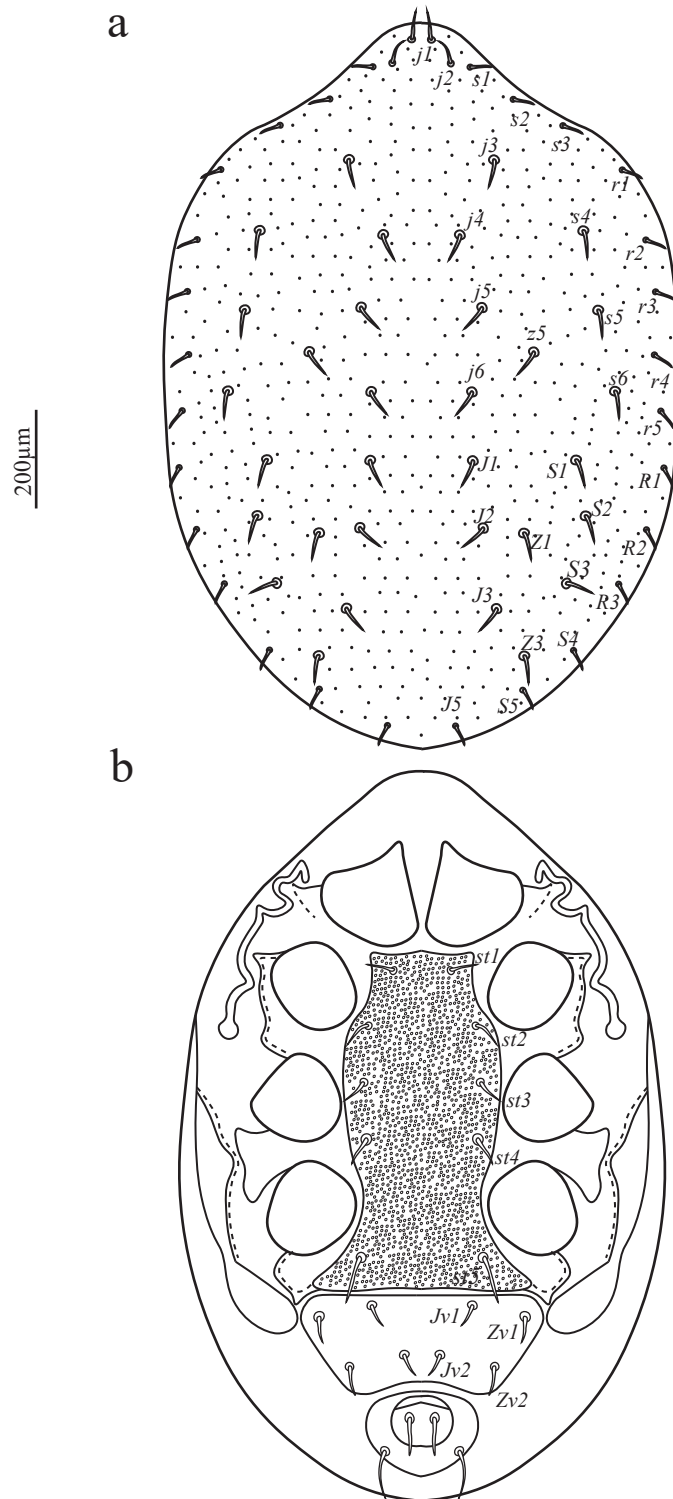


Fig. 1.60. *Uropoda heliocopridis* Deutonymph. a.Dorsal, b.Ventral

Uropoda orbicularis Muller, 1776

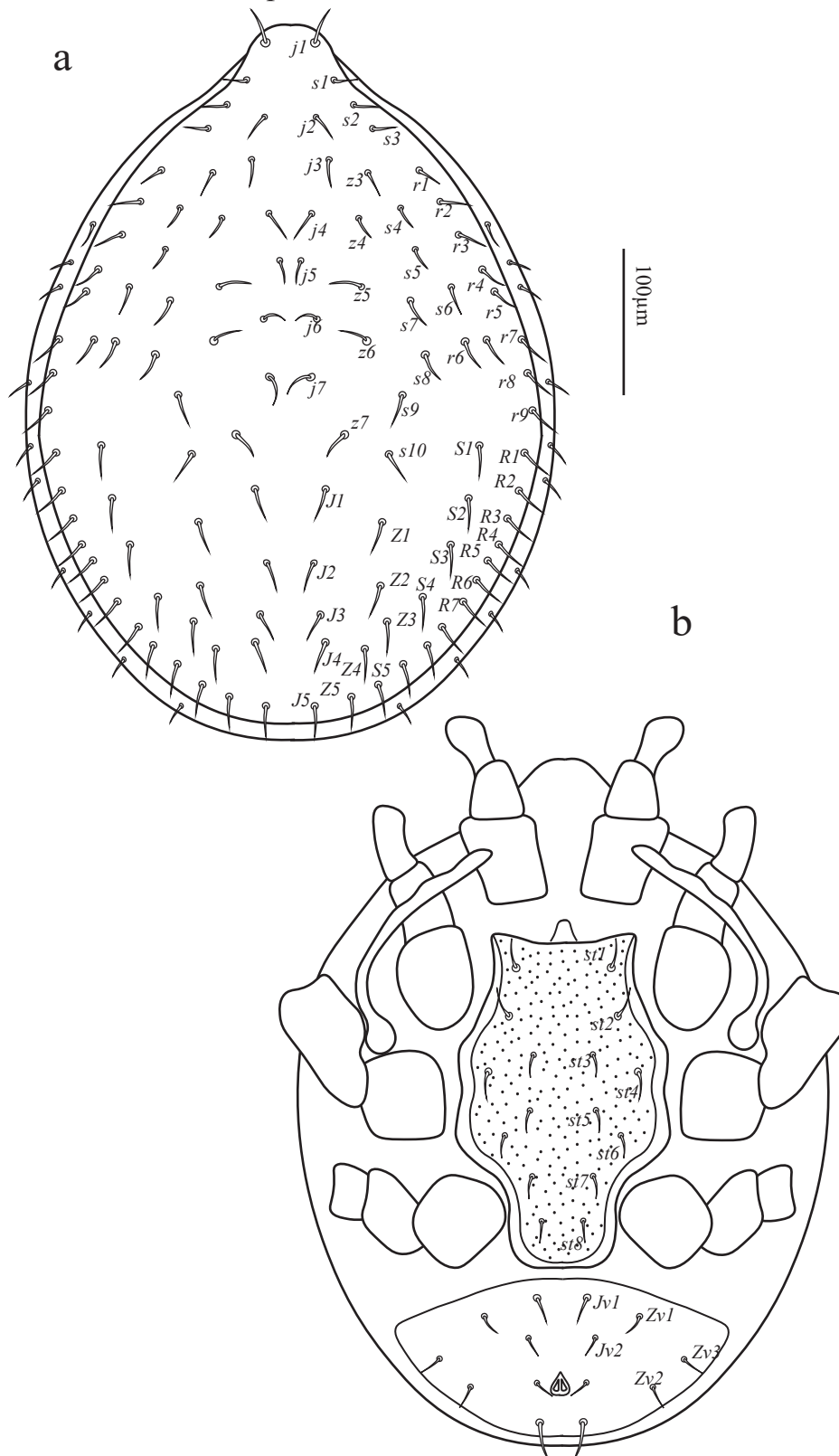


Fig.1.61. *Uropoda orbicularis* Deutonymph. a.Dorsum, b.Venter

Uropoda shangaica Wisneiowski & Hirschmann, 1996

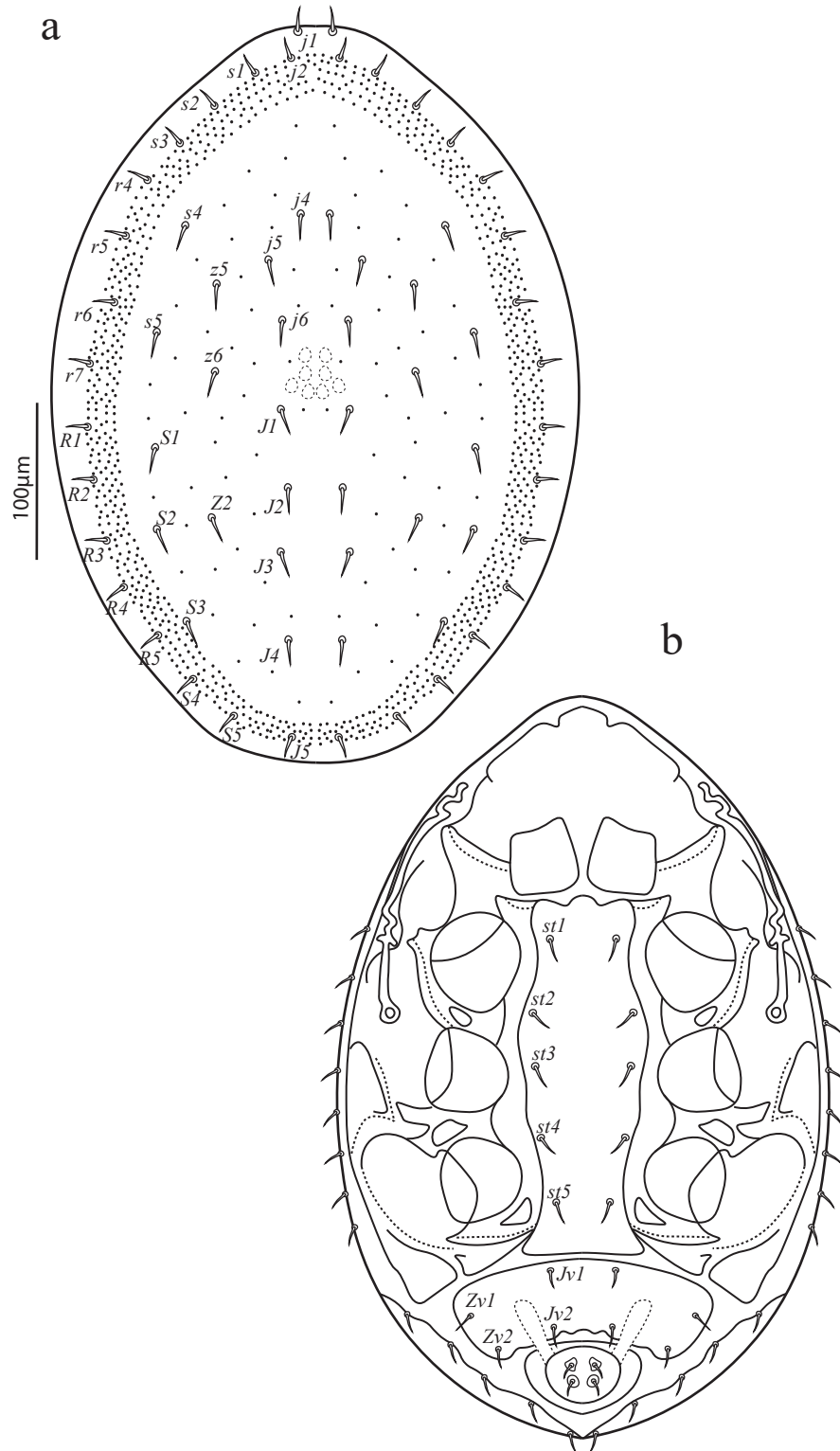


Fig. 1.62. *Uropoda shangaica* Deutonymph. a.Dorsum, b.Venter

Centrouropoda almerodai Hiramatsu & Hirschmann, 1992

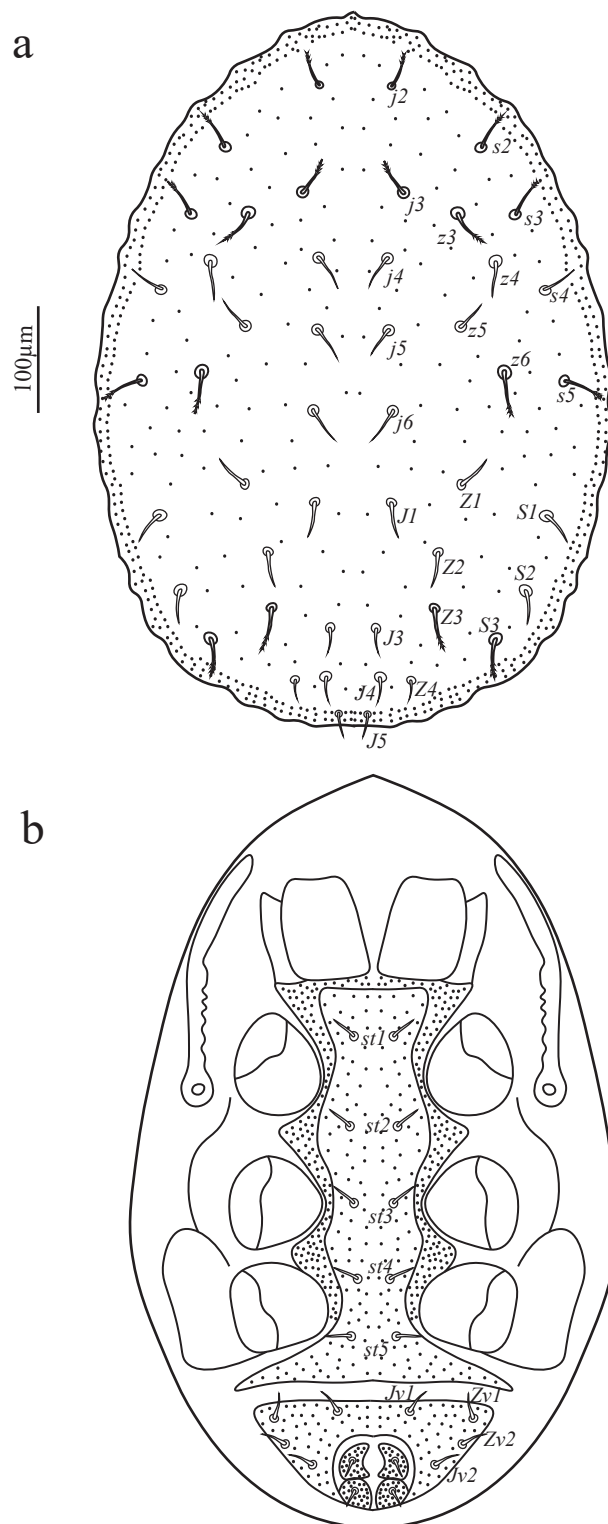


Fig. 1.63. *Centrouropoda almerodai* Deutonymph. a.Dorsum, b.Venter

Uroobovella assamomarginata Hiramatsu & Hirschmann, 1979

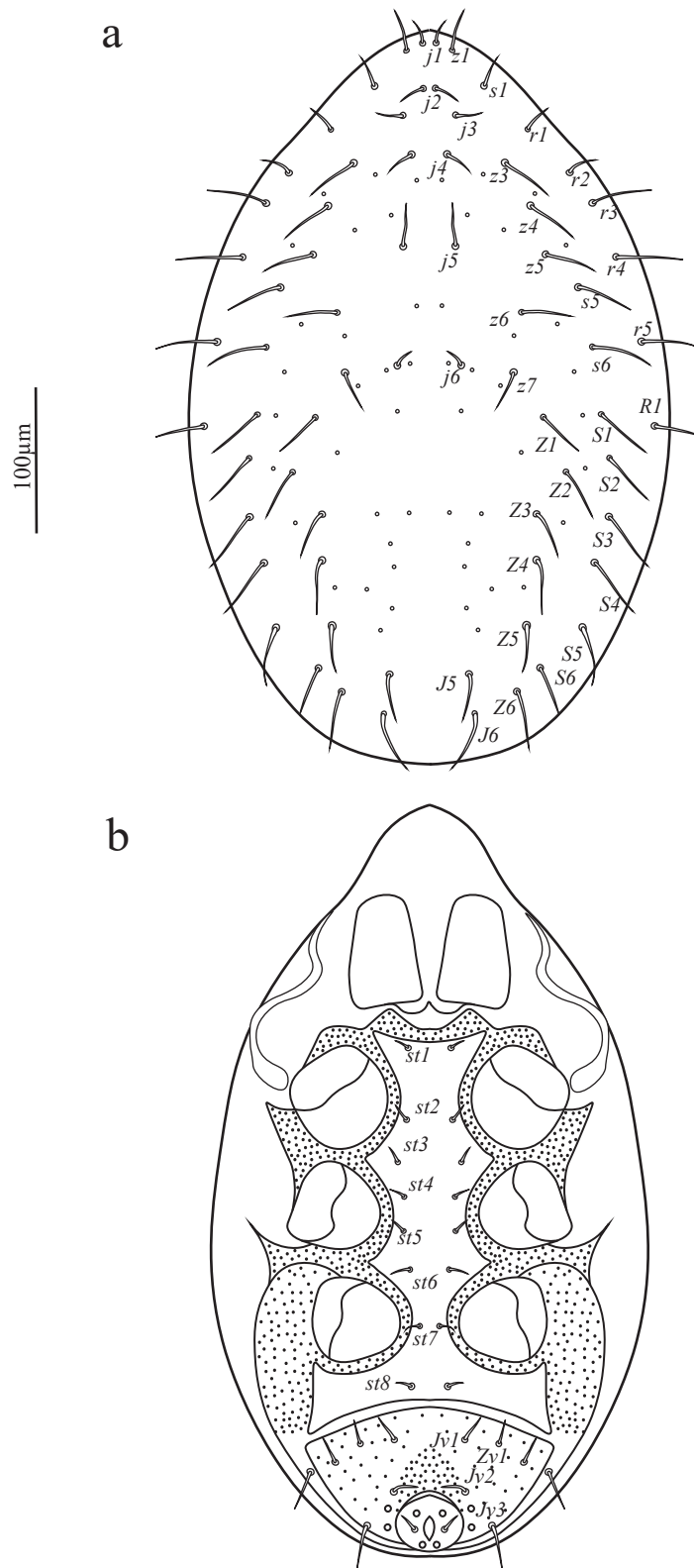


Fig. 1.65. *Uroobovella assamomarginata* Deutonymph a. Dorsum, b. Venter

Uroobovella javae Wisneiowski, 1981

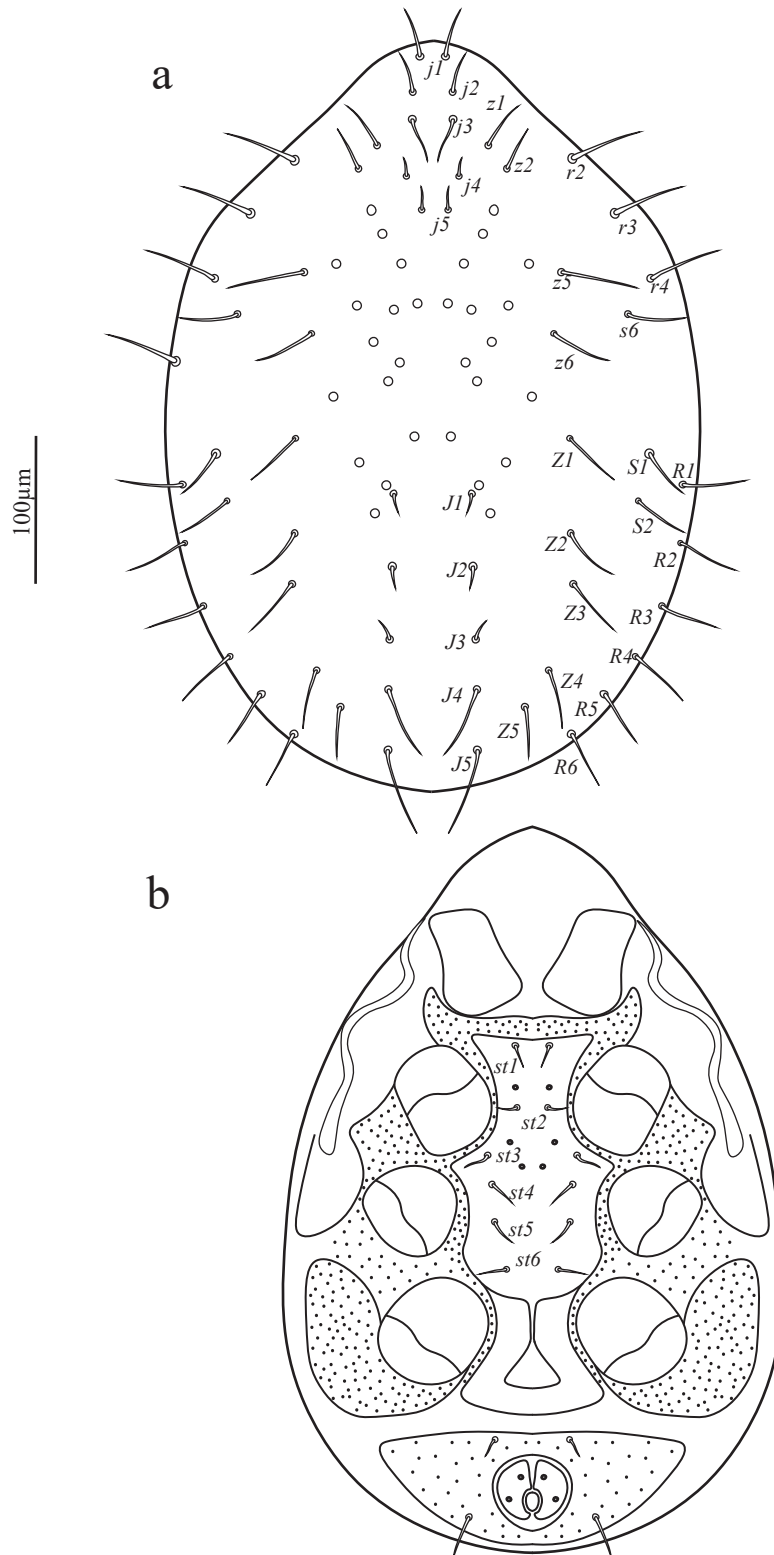


Fig. 1.66. *Uroobovella javae* Deutonymph a. Dorsum, b. Venter

Uroobovella phoenicicola Kontschan, 2012

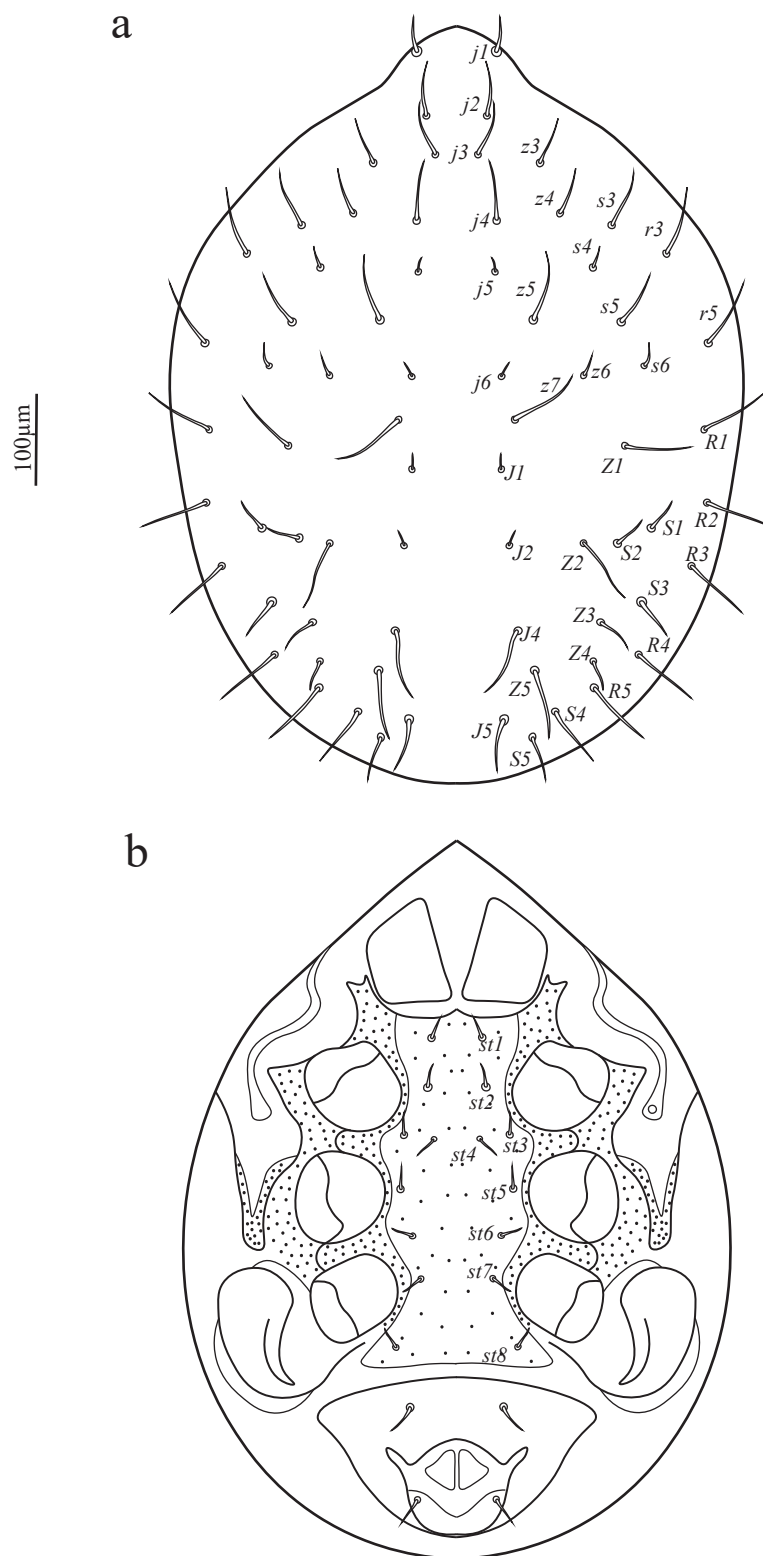


Fig. 1.67. *Uroobovella phoenicicola* Deutonymph a.Dorsum, b.Venter

Uroobovella pilosetosa Kontschan, 2012

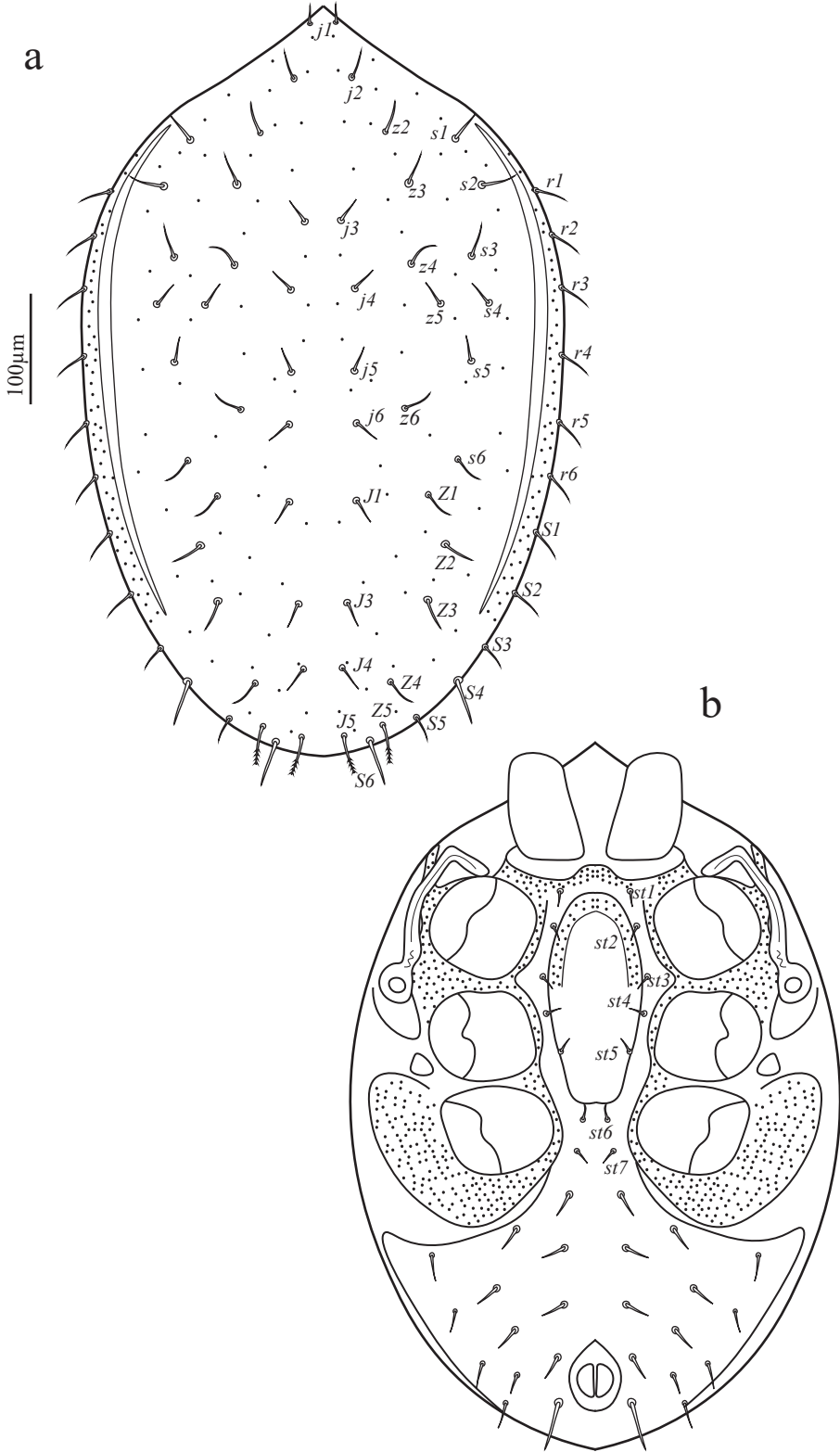


Fig. 1.68. *Uroobovella pilosetosa* Adult female. a.Dorsum, b. Venter

Holoparasitus stramenti Karg, 1971

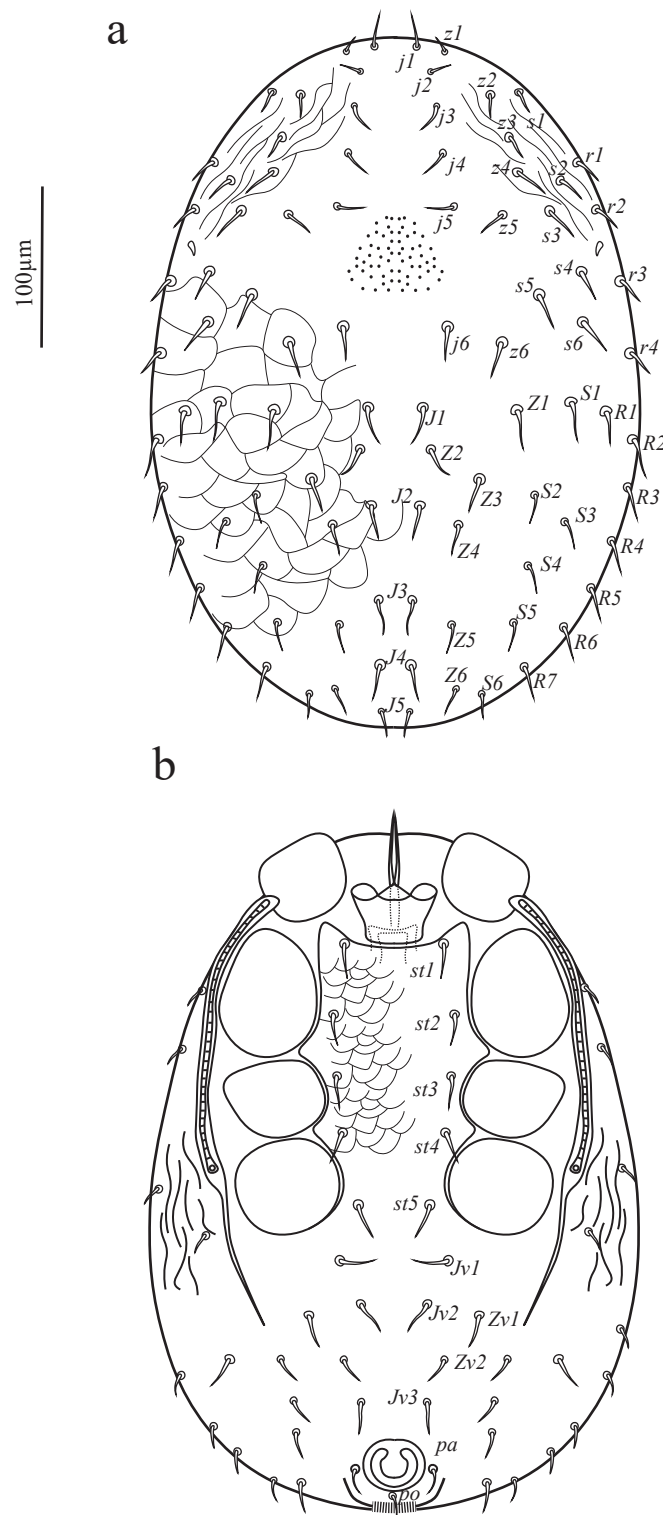


Fig. 1.69. *Holoparasitus stramenti* Adult male. a.Dorsal, b.Ventral

Poechilochirus sp.

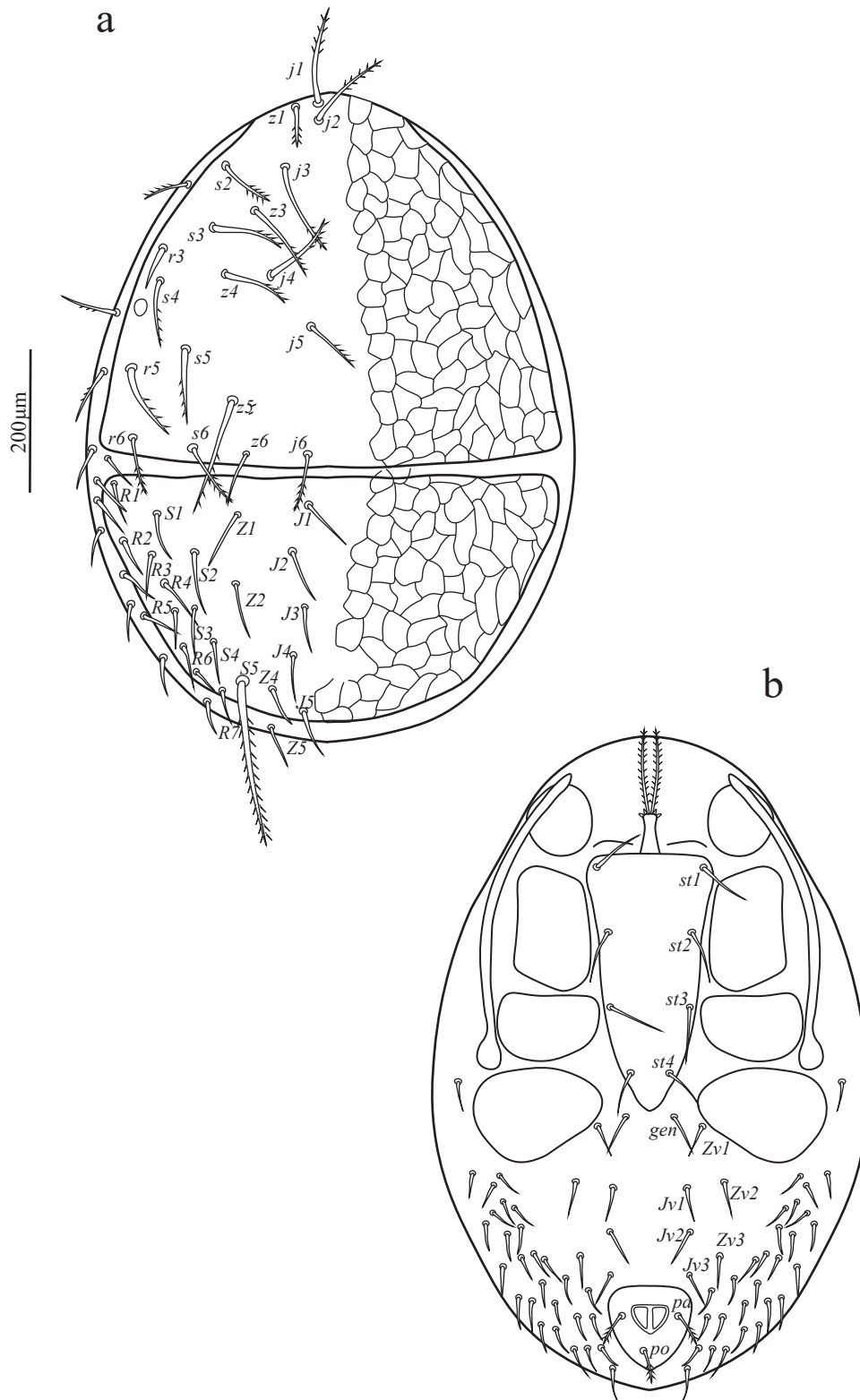


Fig. 1.70. *Poechilochirus* sp. Deutonymph a.Dorsum, b.Venter.

Digamasellus neodisetus Hurlbutt, 1967

a



b

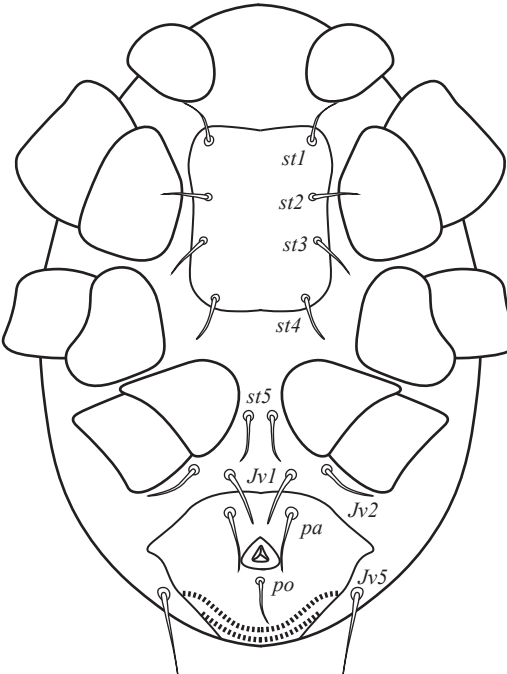


Fig. 1.71. *Digamasellus neodisetus* Protonymph a.Dorsum, b.Venter

Digamasellus quadrisetus (Berlese, 1921)

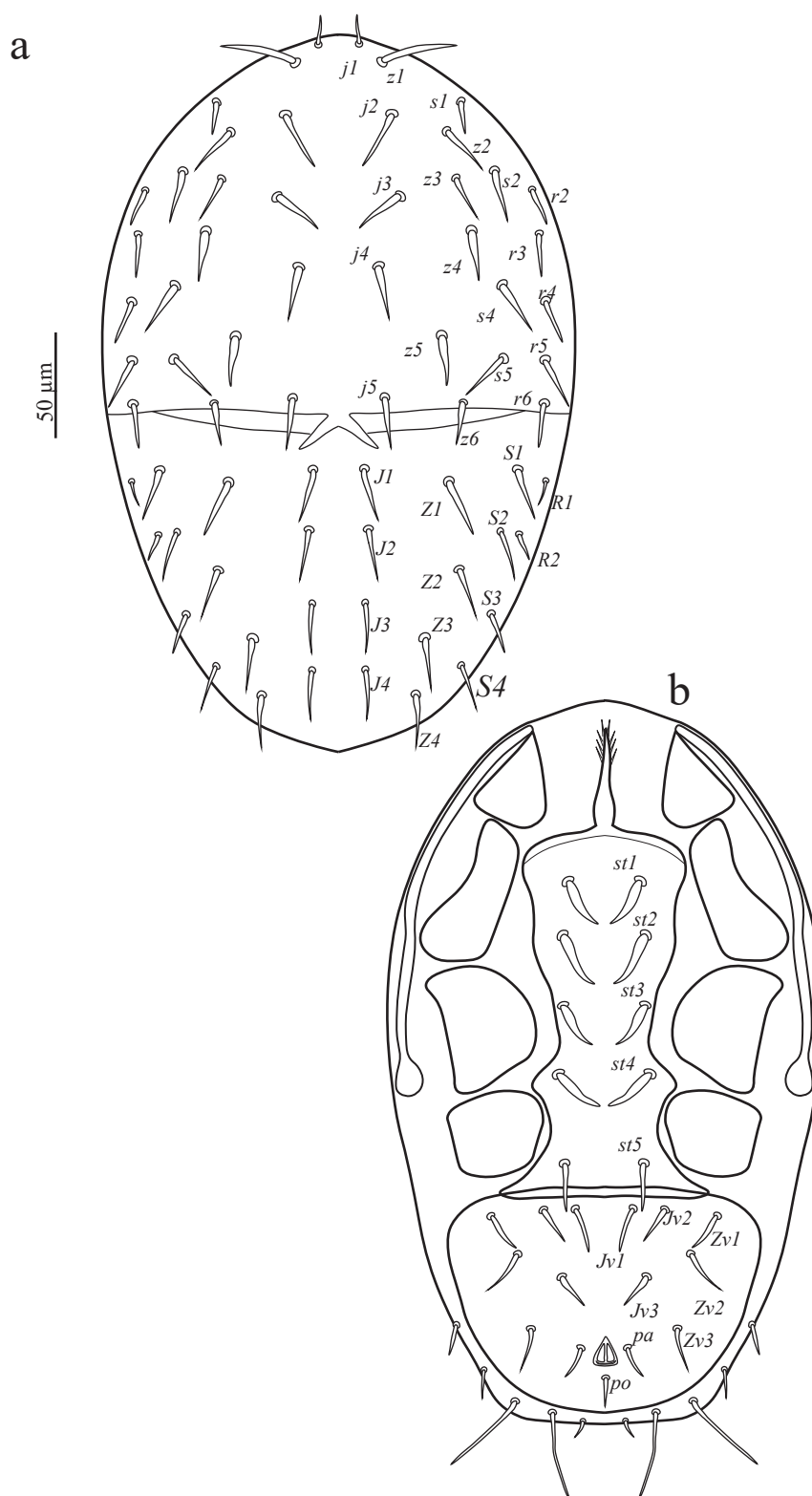


Fig. 1.72. *Digamasellus quadrisetus* Deutonymph a.Dorsum, b.Venter

Alliphis halleri (G. R. Canestrini, 1881)

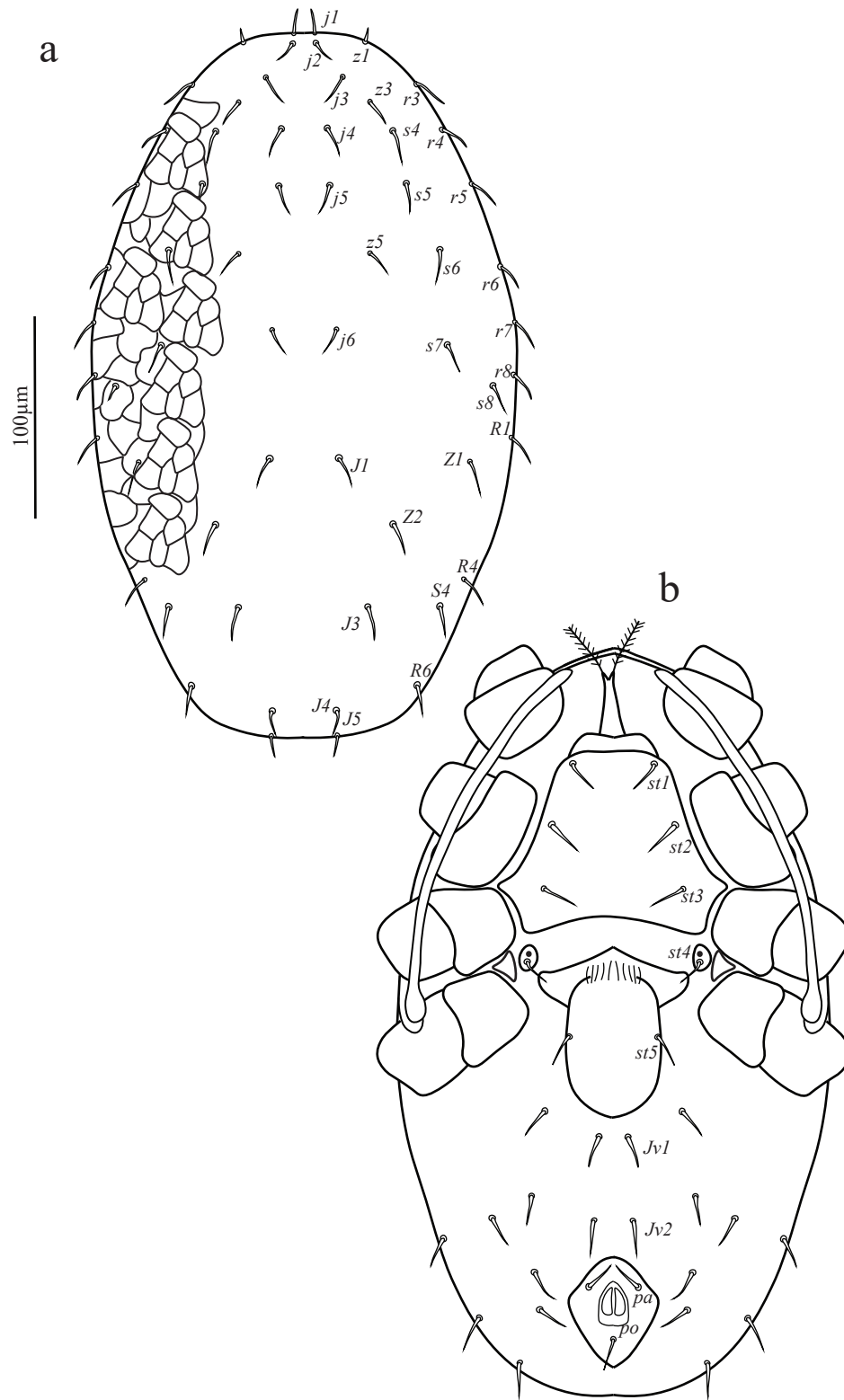


Fig. 1.73. *Alliphis halleri* Adult female. a.Dorsum, b.Venter

Alliphis sp.

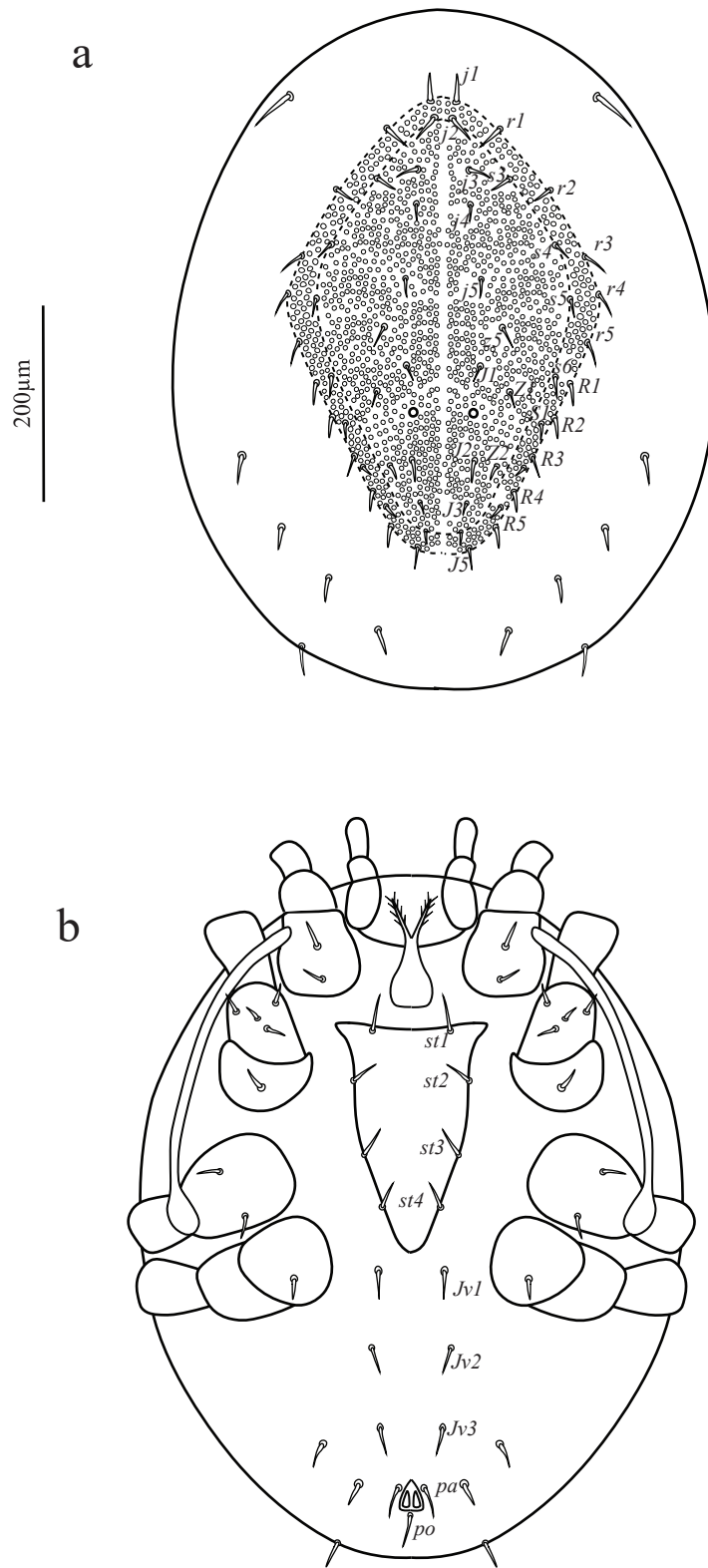


Fig.1.74. *Alliphis* sp. Deutonymph a. Dorsum, b. Venter

Macrocheles glaber (Muller, 1860)

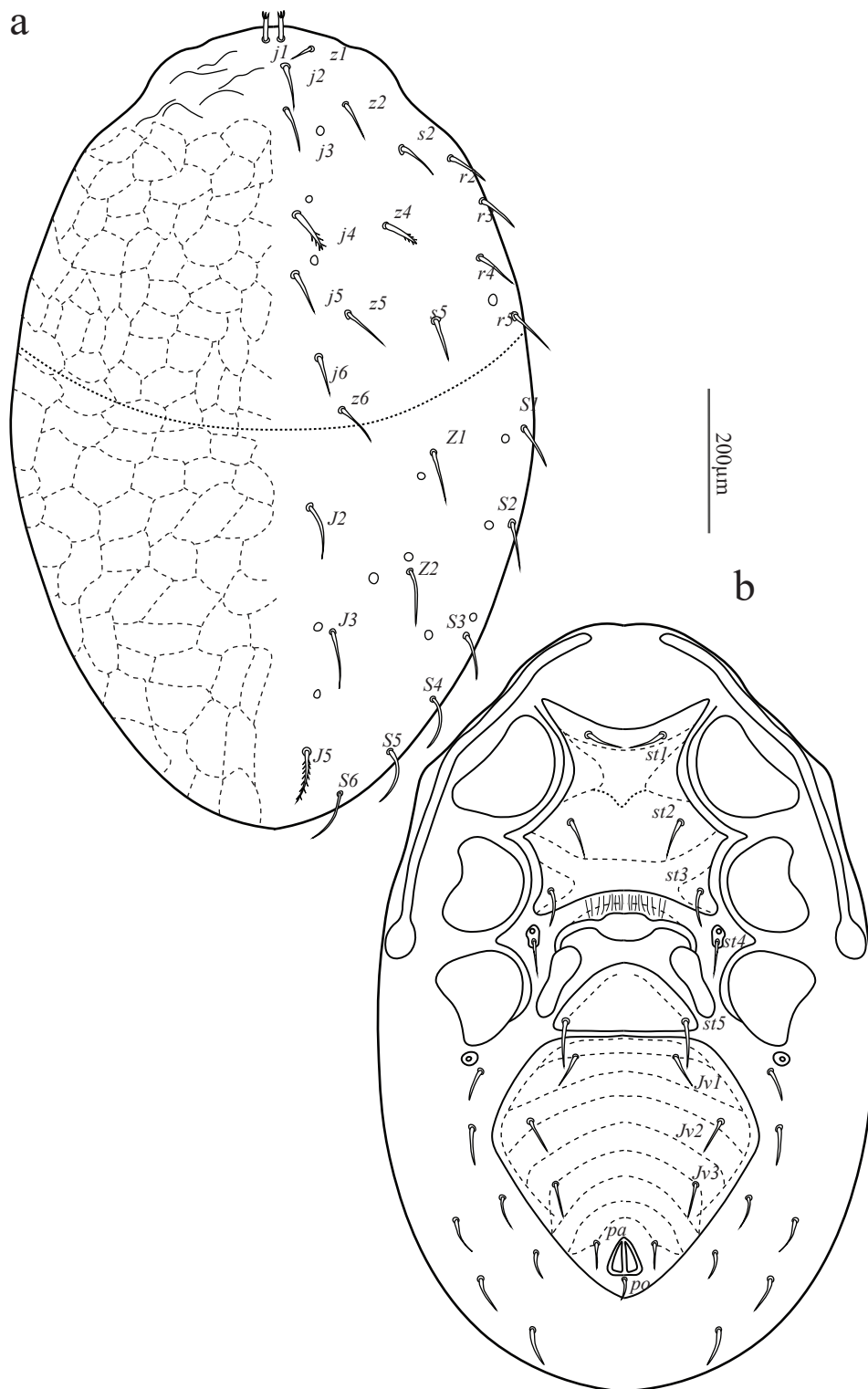


Fig. 1.75. *Macrocheles glaber* Adult female a.Dorsal, b.Venter

Macrocheles krantzi (Evans and Hyatt, 1963)

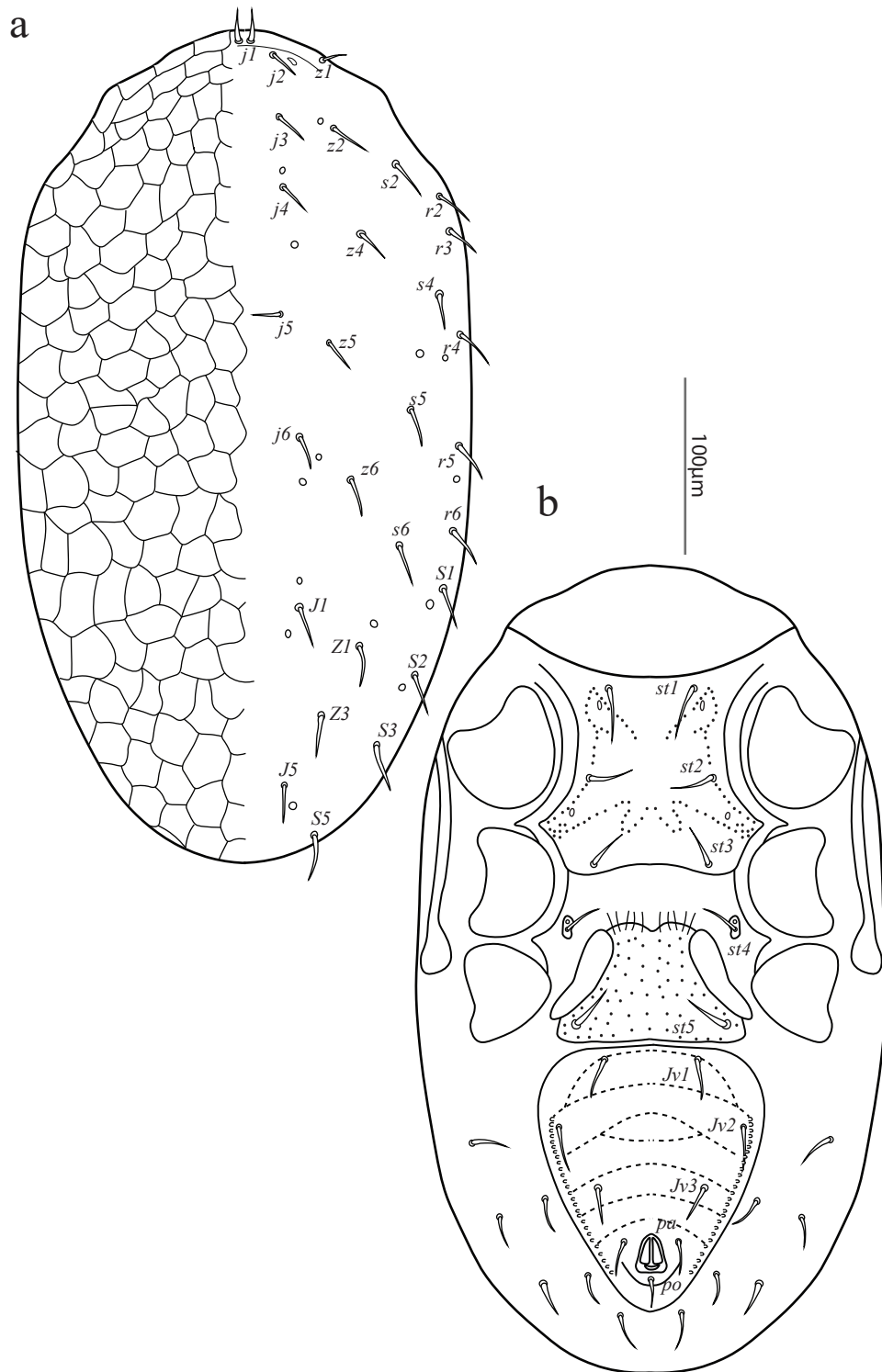


Fig. 1.76. *Macrocheles krantzi* Adult female a.Dorsum, b.Venter

Macrocheles muscaedomesticae (Scopoli, 1772)

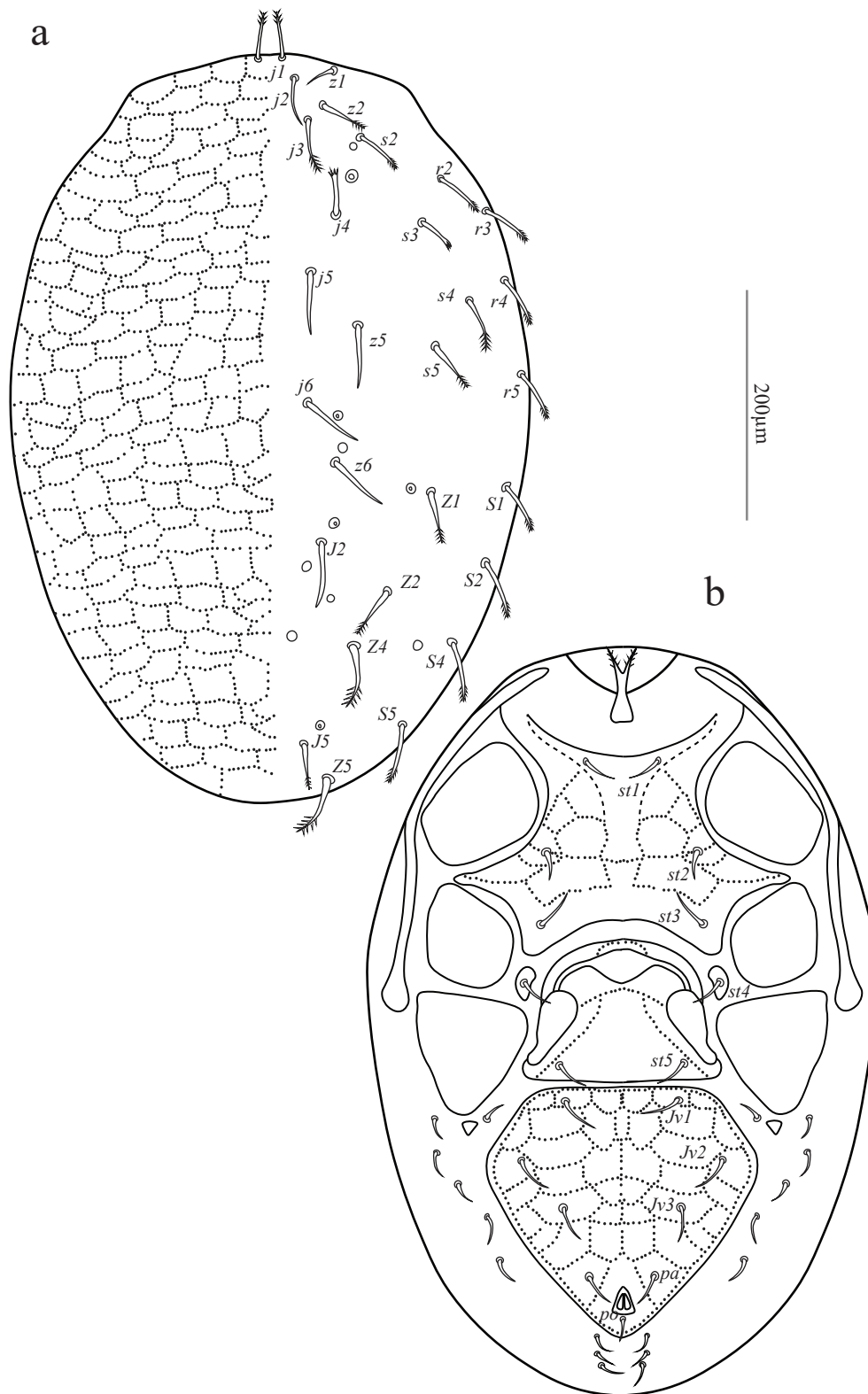


Fig.1.77. *Macrocheles muscaedomesticae* Adult female a.Dorsum,
b.Venter

Macrocheles perglaber Filipponi & Pegazzano, 1962

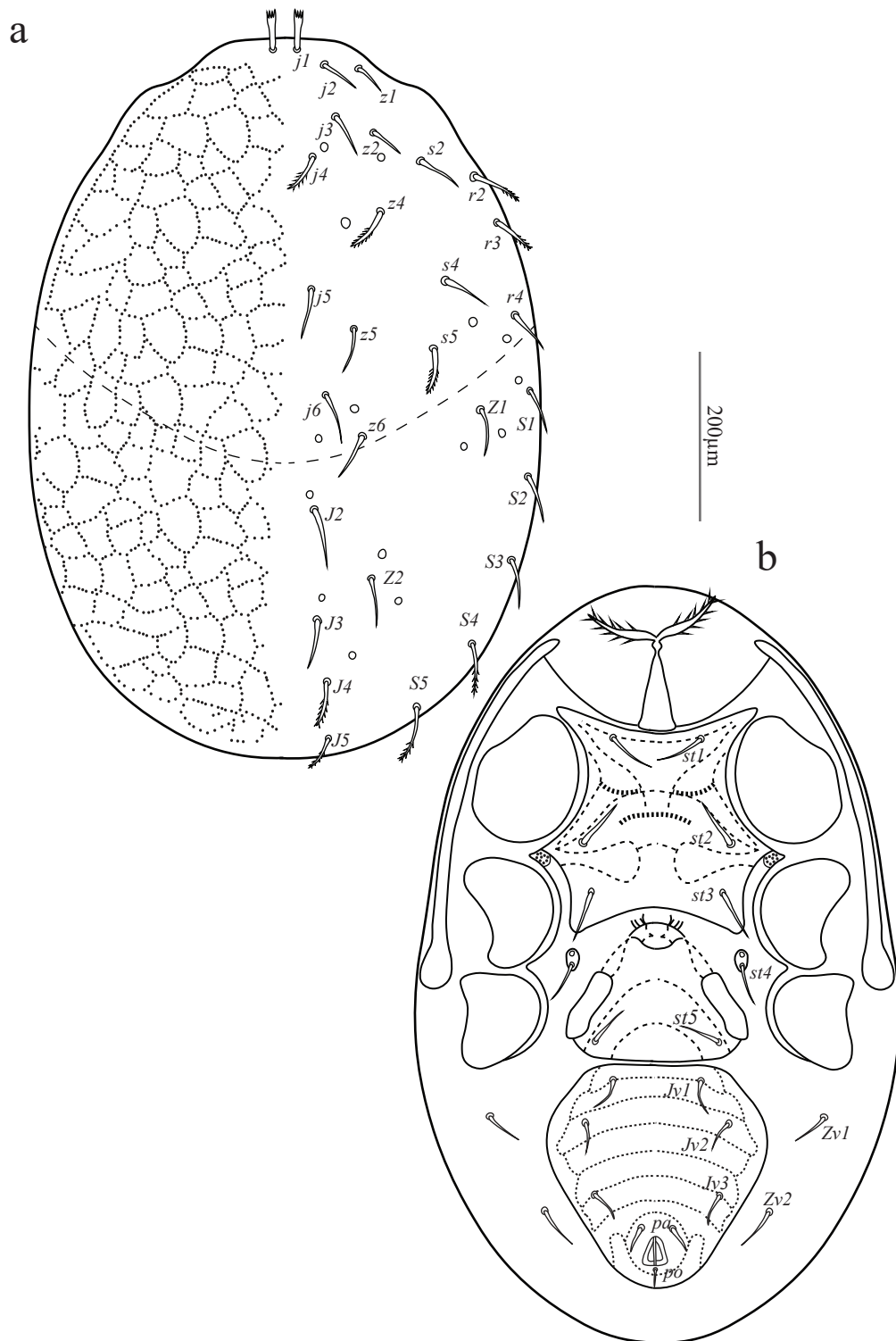
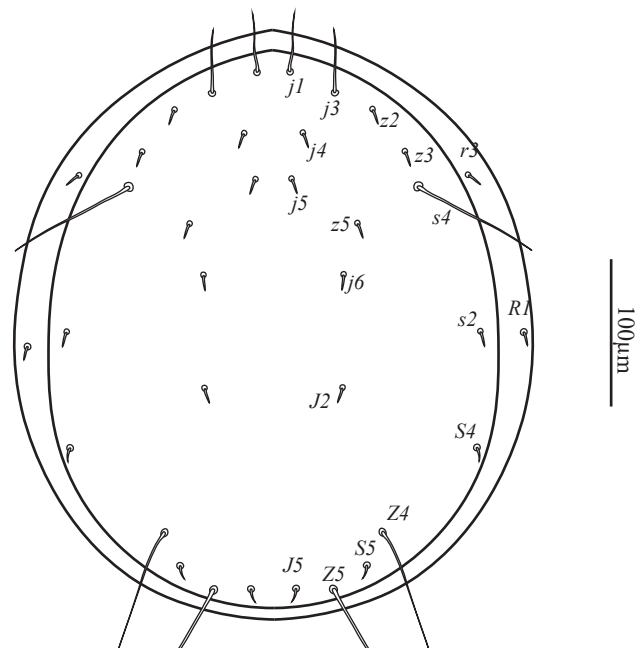


Fig. 1.78. *Macrocheles perglaber* Adult female a. Dorsum, b. Venter

Amblyseius channabasavannai Gupta & Daniel, 1978

a



b

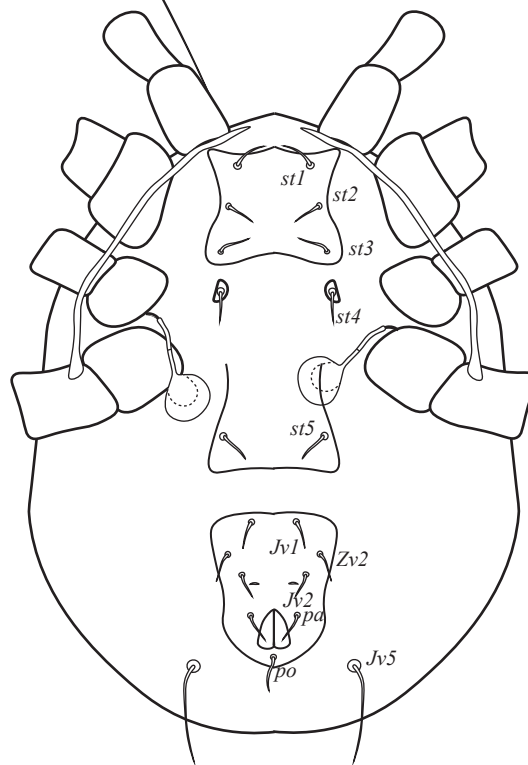


Fig. 1.79. *Amblyseius channabasavannai* a.Dorsum,b.Venter

Ambyseius largoensis (Muma, 1955)

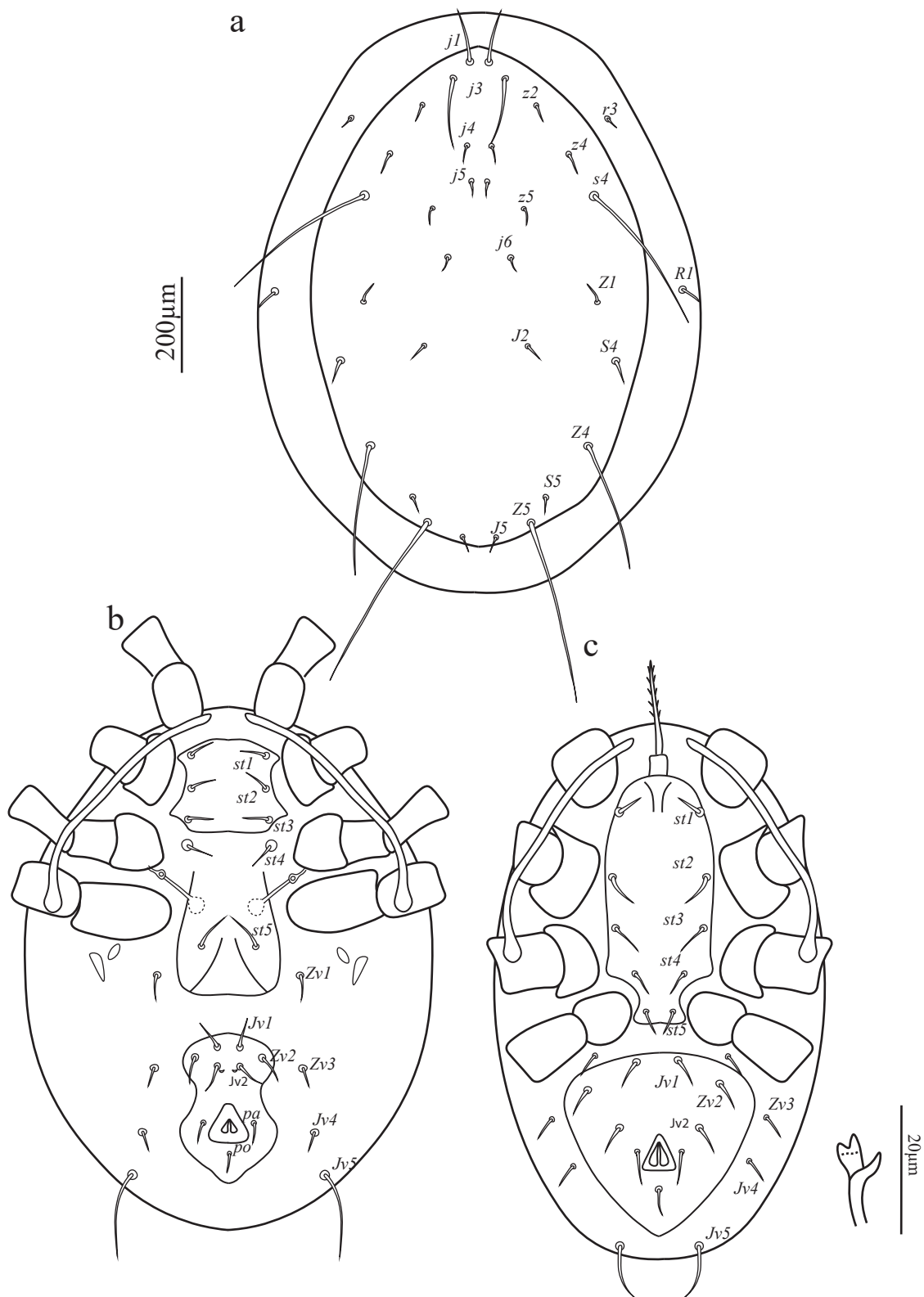


Fig.1.80. *Ambyseius largoensis* a.Dorsum, b.Venter of Adult female, c.Venter of Adult male.

Amblyseius vasiformis Moraes & Mesa, 1991

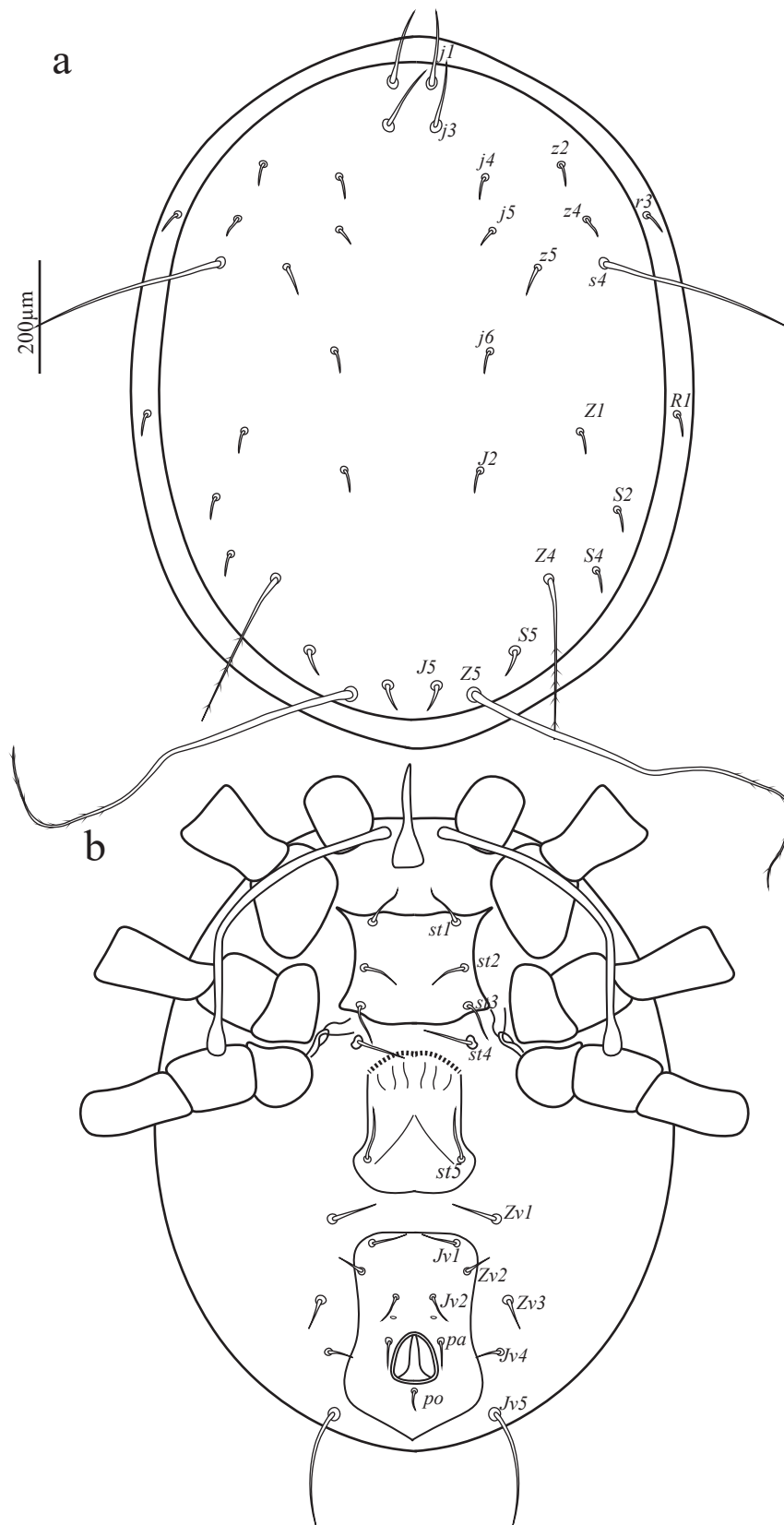


Fig.1.81. *Amblyseius vasiformis* Adult female a.Dorsum, b.Venter

Neoseiulus mapuche Ferragut & Navia, 2015

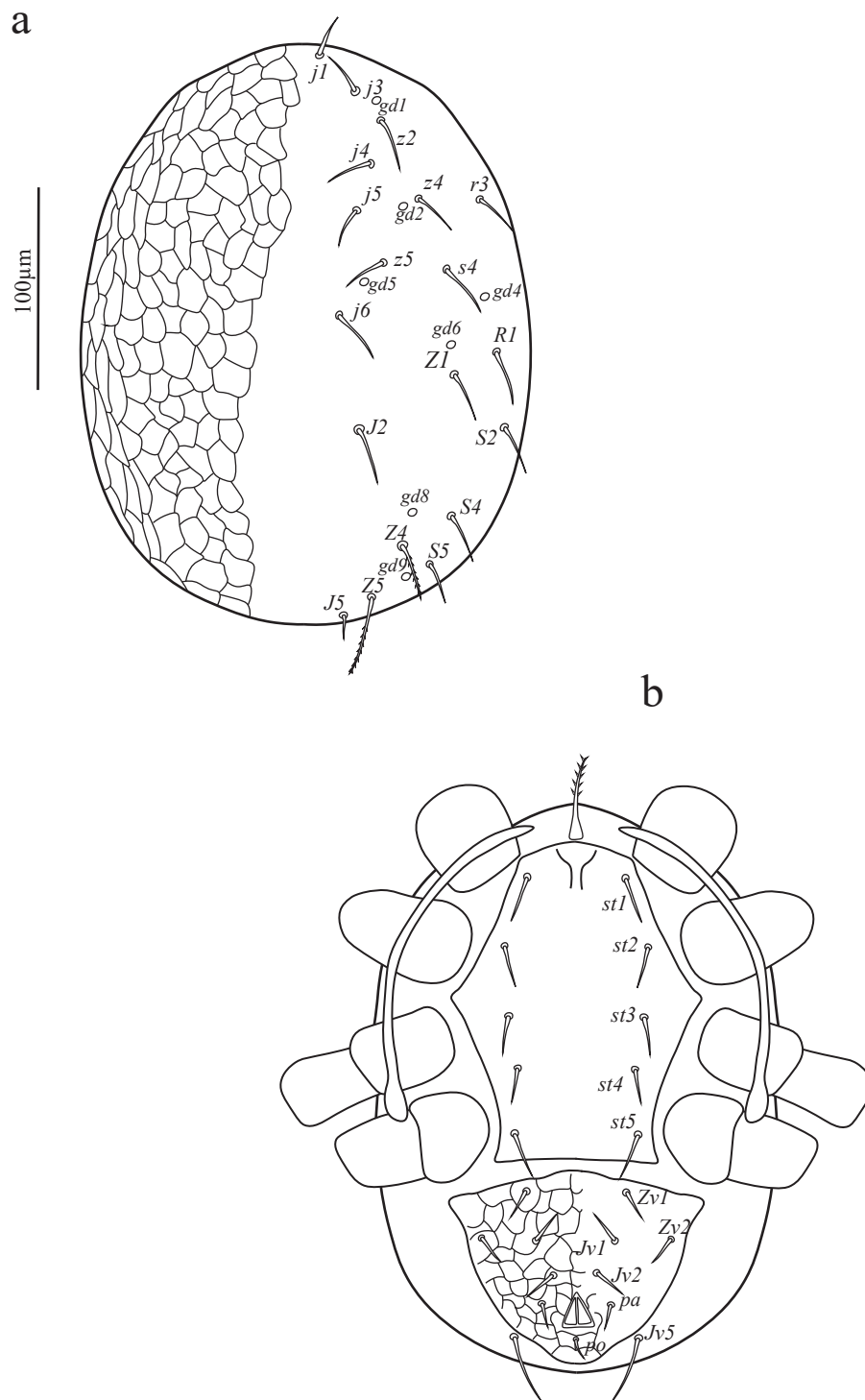


Fig. 1.82. *Neoseiulus mapuche* Adult male a.Dorsum, b.Venter

Euseius finlandicus (Oudemans, 1915)

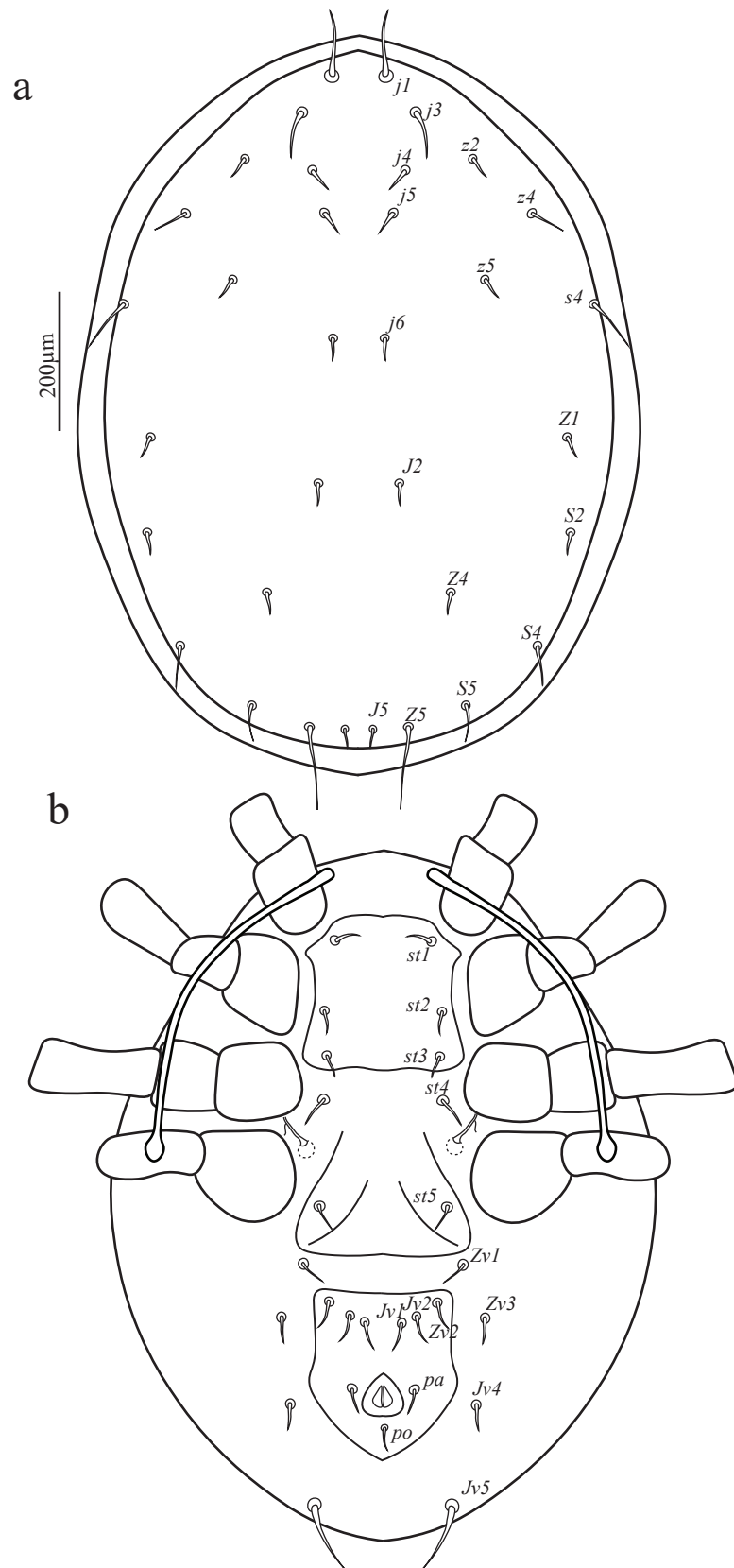


Fig. 1.83. *Euseius finlandicus* Adult female a.Dorsum, b.Venter

Euseius ovalis (Evans, 1953)

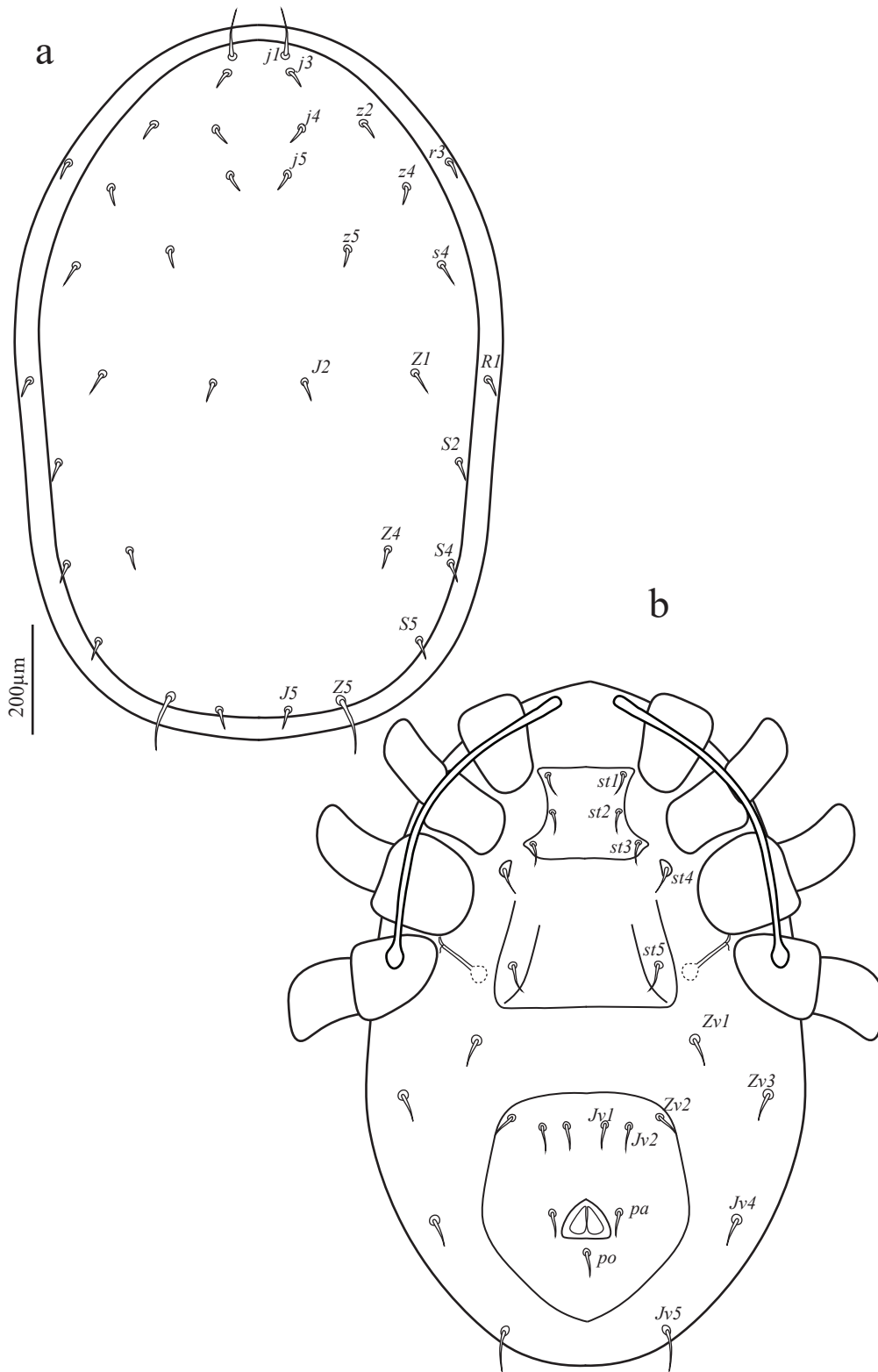
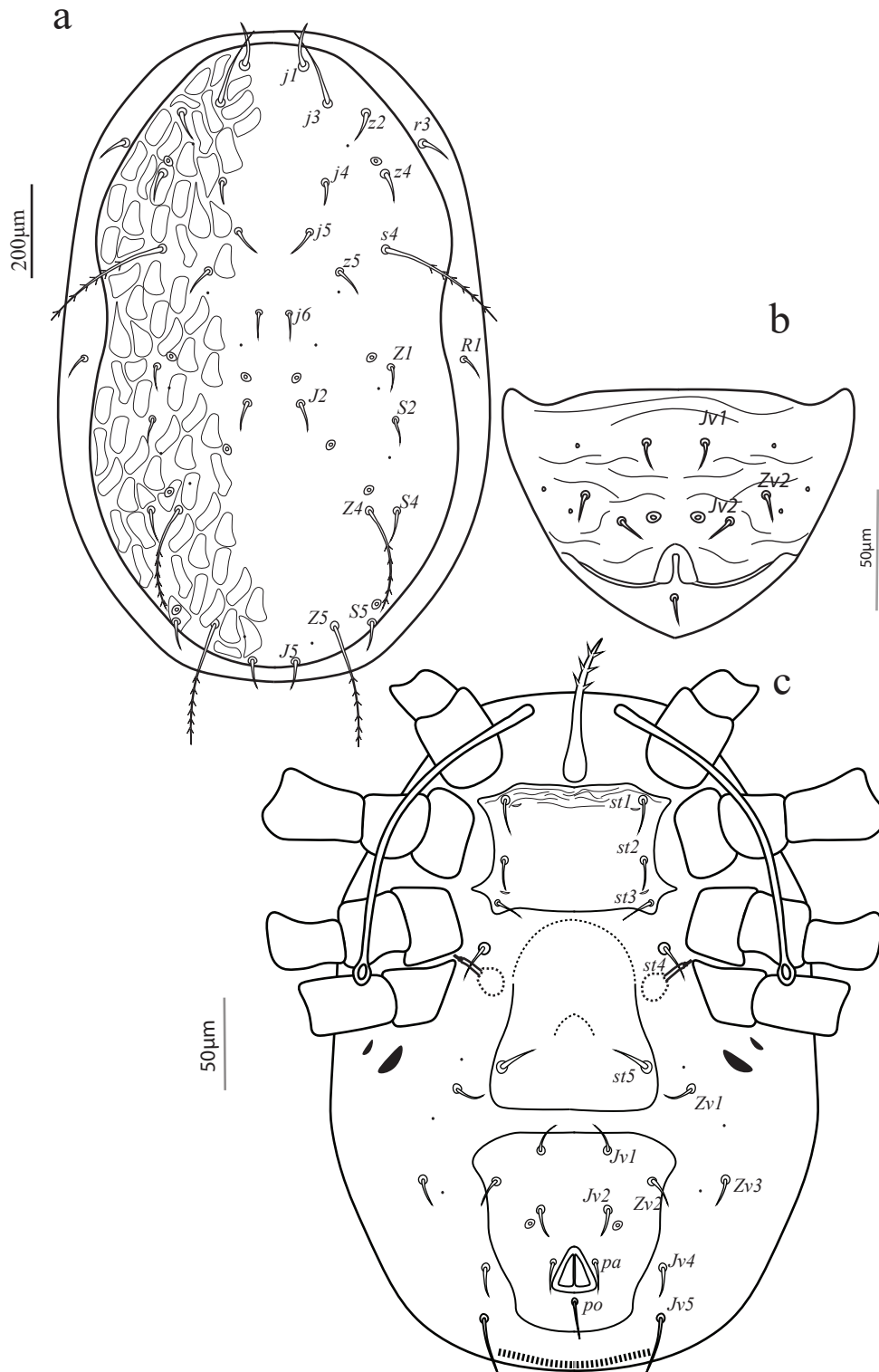


Fig.1.84. *Euseius ovalis* Adult female a.Dorsum, b.Venter



Lasioseius confusus Evans, 1958

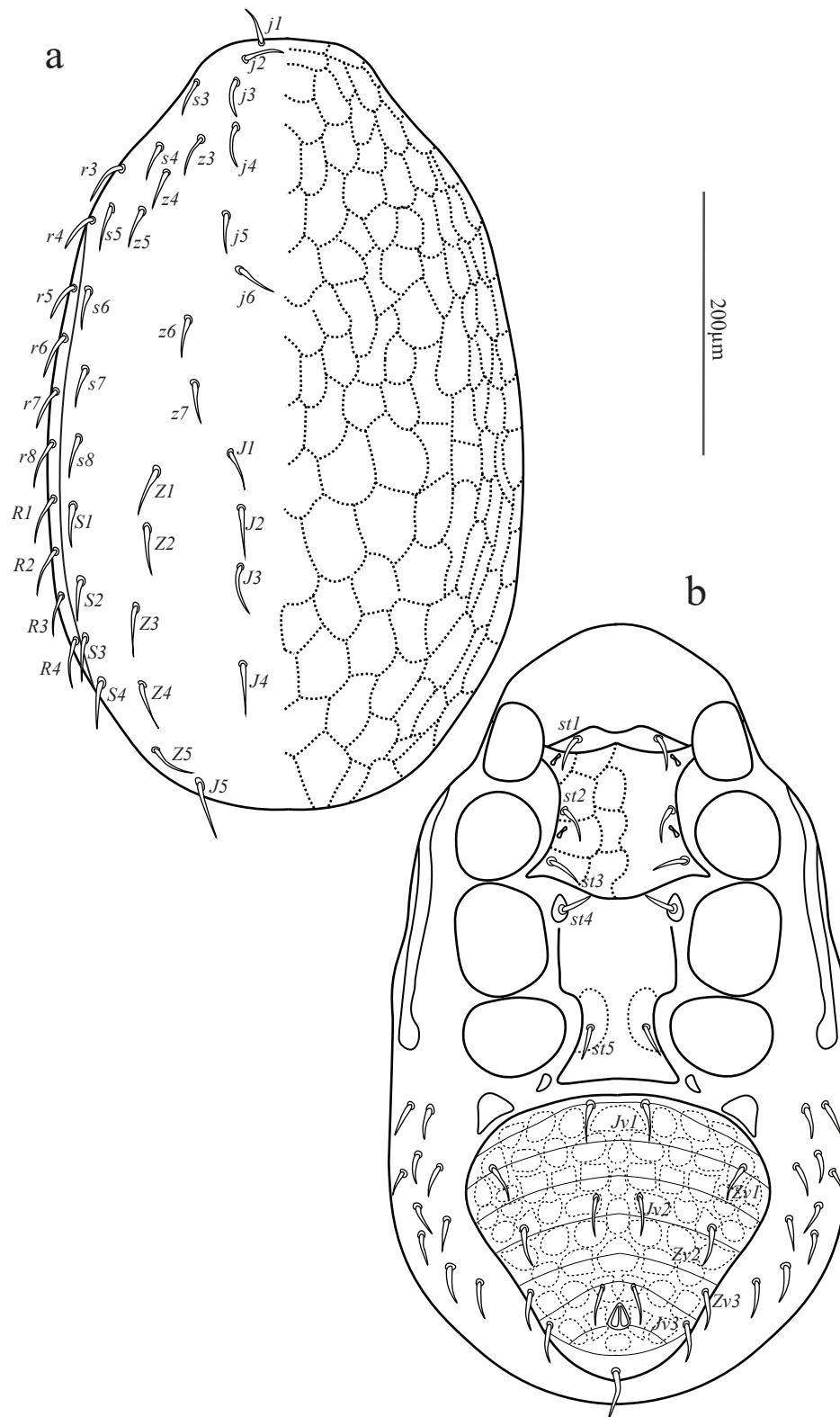


Fig. 1.86. *Lasioseius confusus* Adult female a.Dorsum, b.Venter

Lasioseius (Lasioseius) moolamkudensis sp. nov.

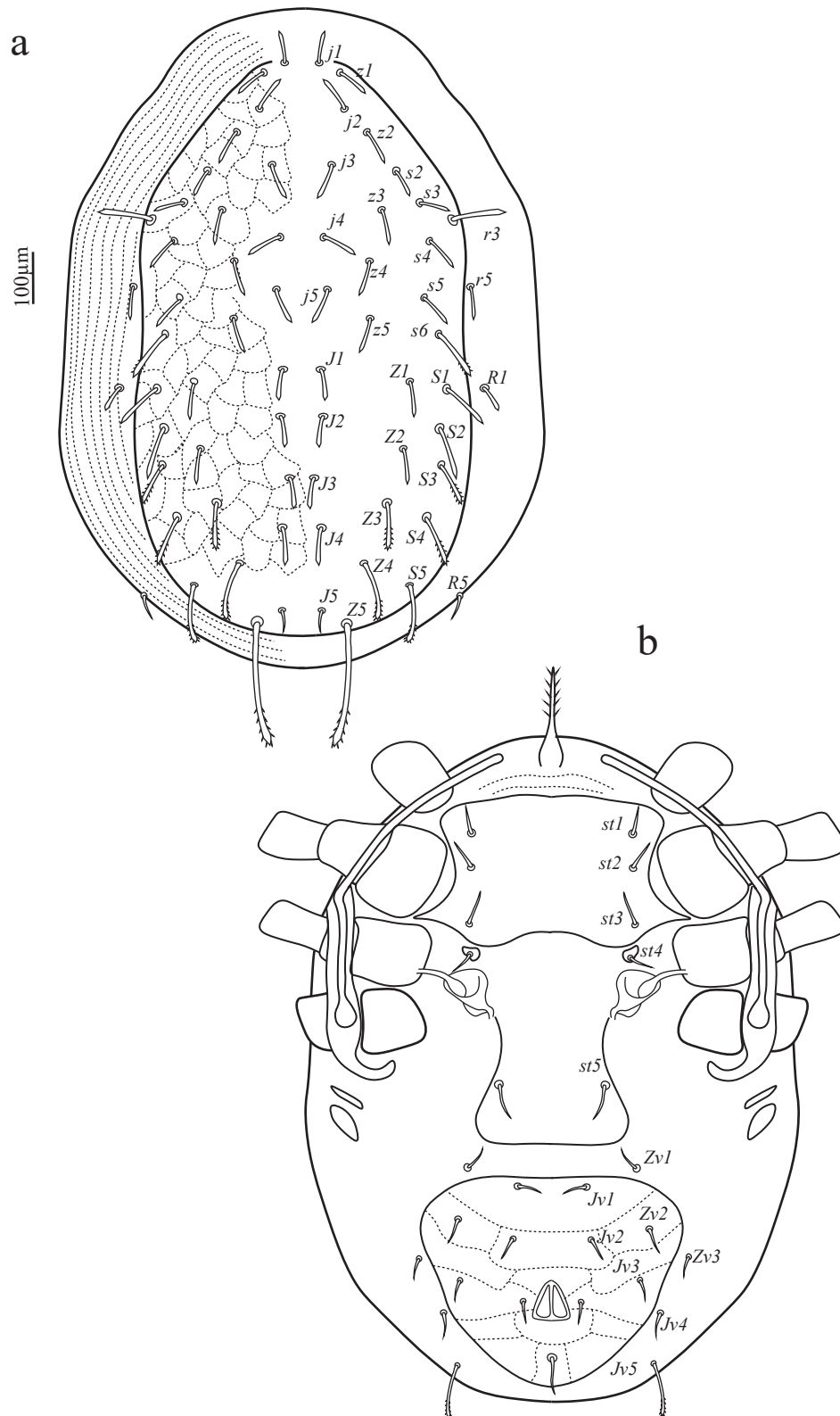


Fig. 1.87. *Lasioseius (Lasioseius) moolamkudensis* sp. nov. Adult female. a.Dorsum, b.Venter

Lasioseius (Lasioseius) moolamkudensis sp. nov.

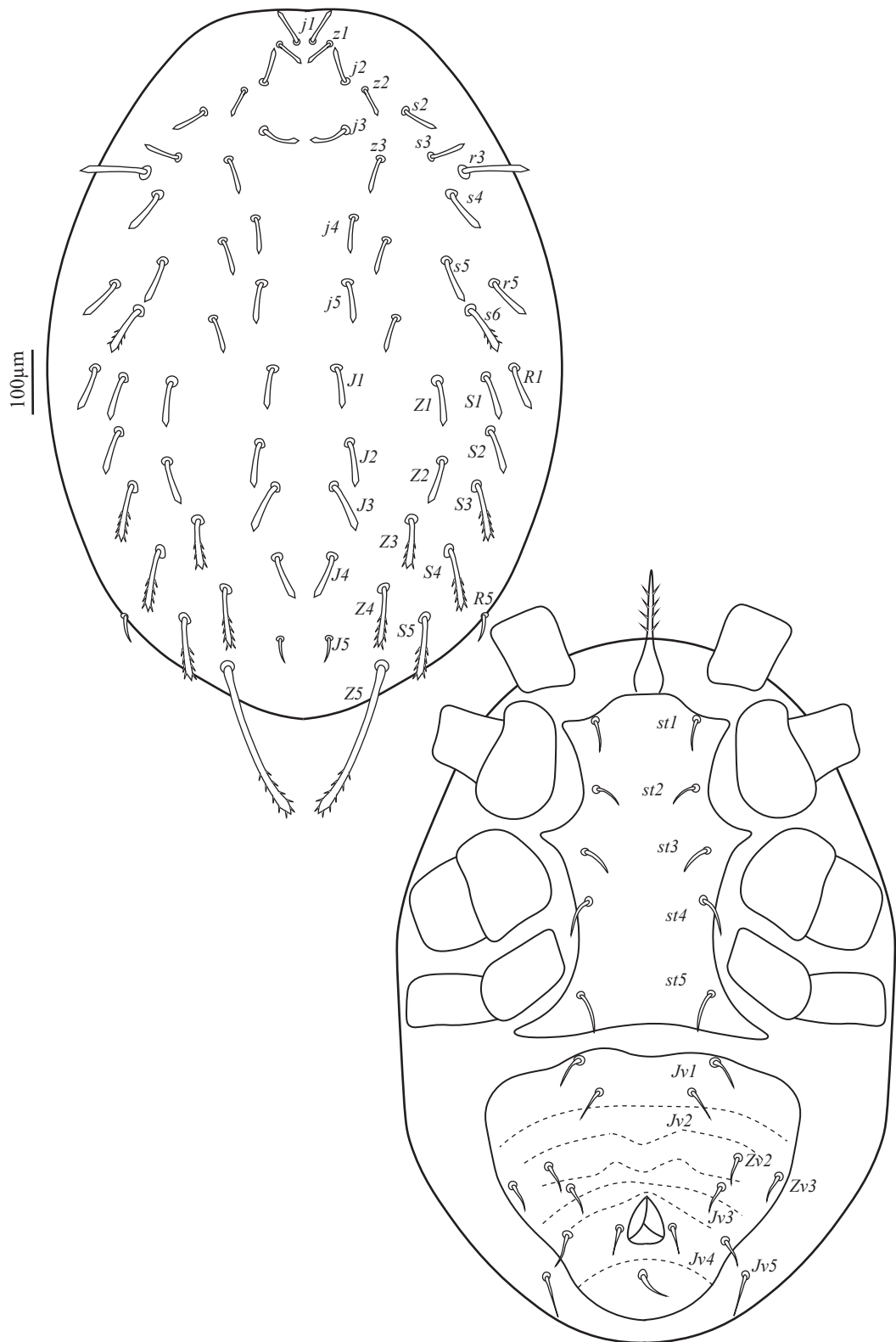


Fig. 1.88. *Lasioseius (Lasioseius) moolamkudensis* sp. nov. Adult male.
a.Dorsum, b.Venter

Lasioseius (Lasioseius) moolamkudensis sp. nov.

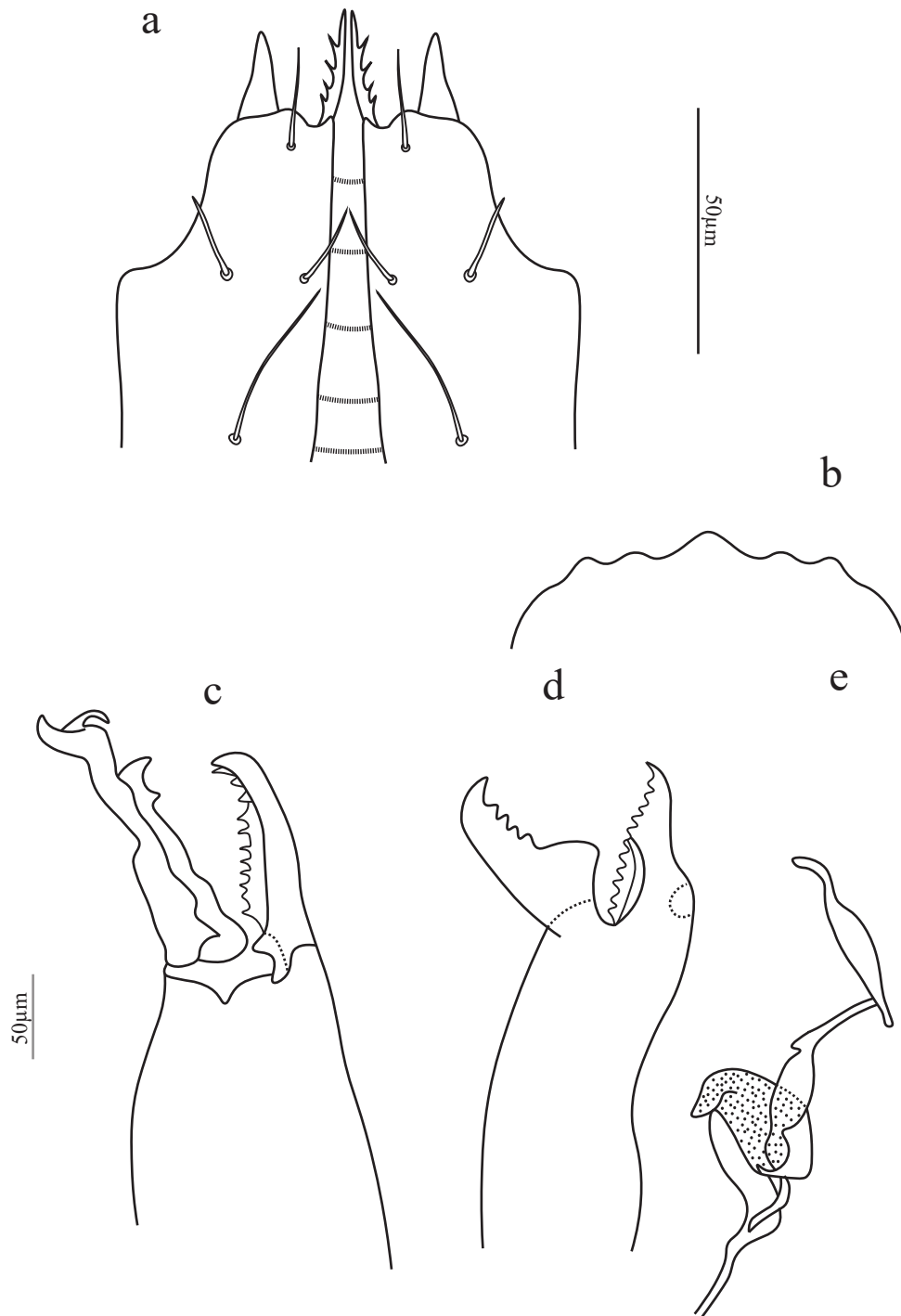


Fig. 1.89. *Lasioseius (Lasioseius) moolamkudensis* sp. nov.
a. Subcapitulum, b. Gnathotectum, c. Chelicera of male, d. Chelicera of female, e. Sperm access system of female.

Lasioseius (Lasioseius) moolamkudensis sp. nov.

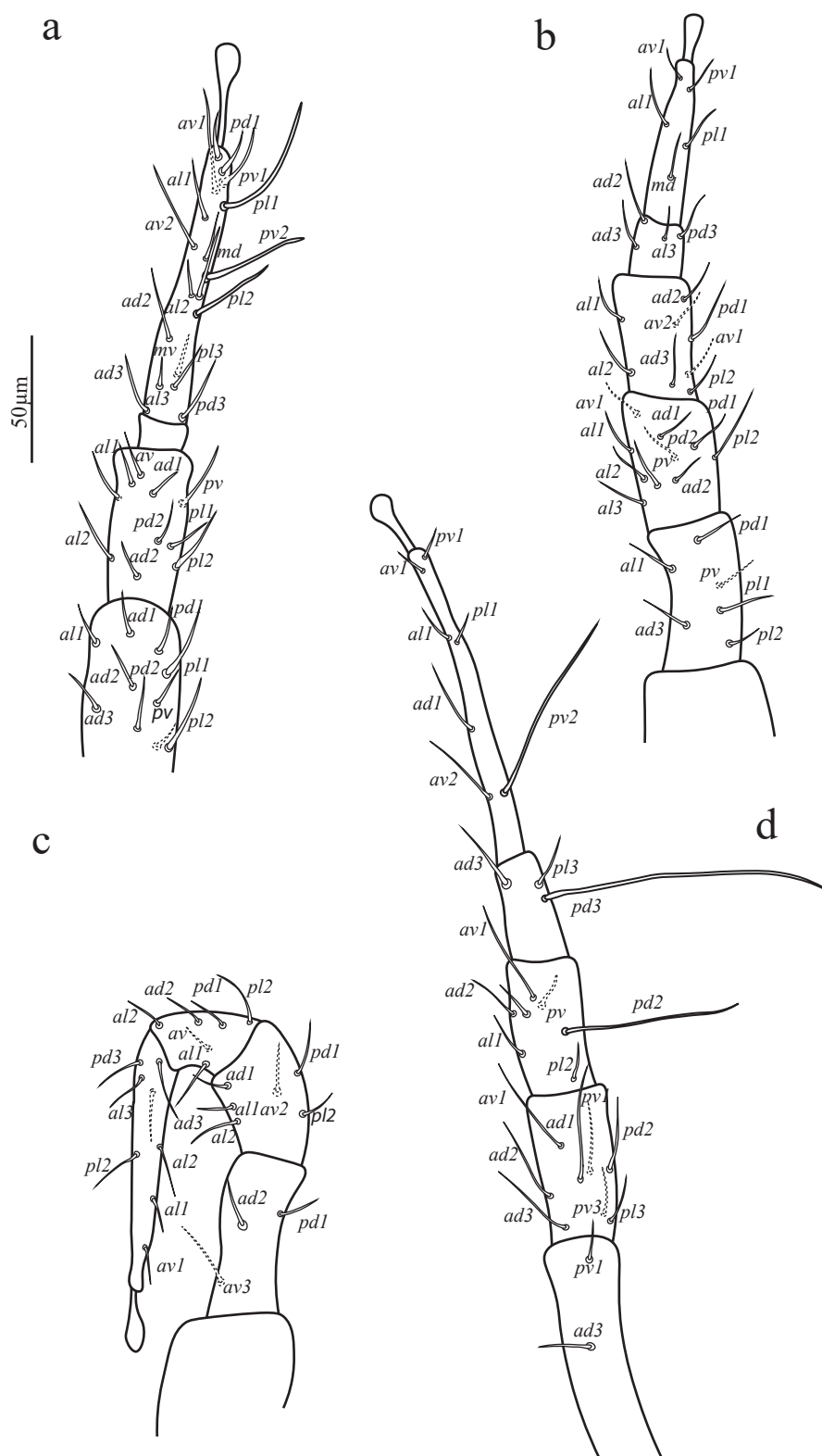


Fig. 1.90. *Lasioseius (Lasioseius) moolamkudensis* sp. nov. a.Leg I, b.Leg II, c.Leg III, d.Leg IV

Laelaps sp.

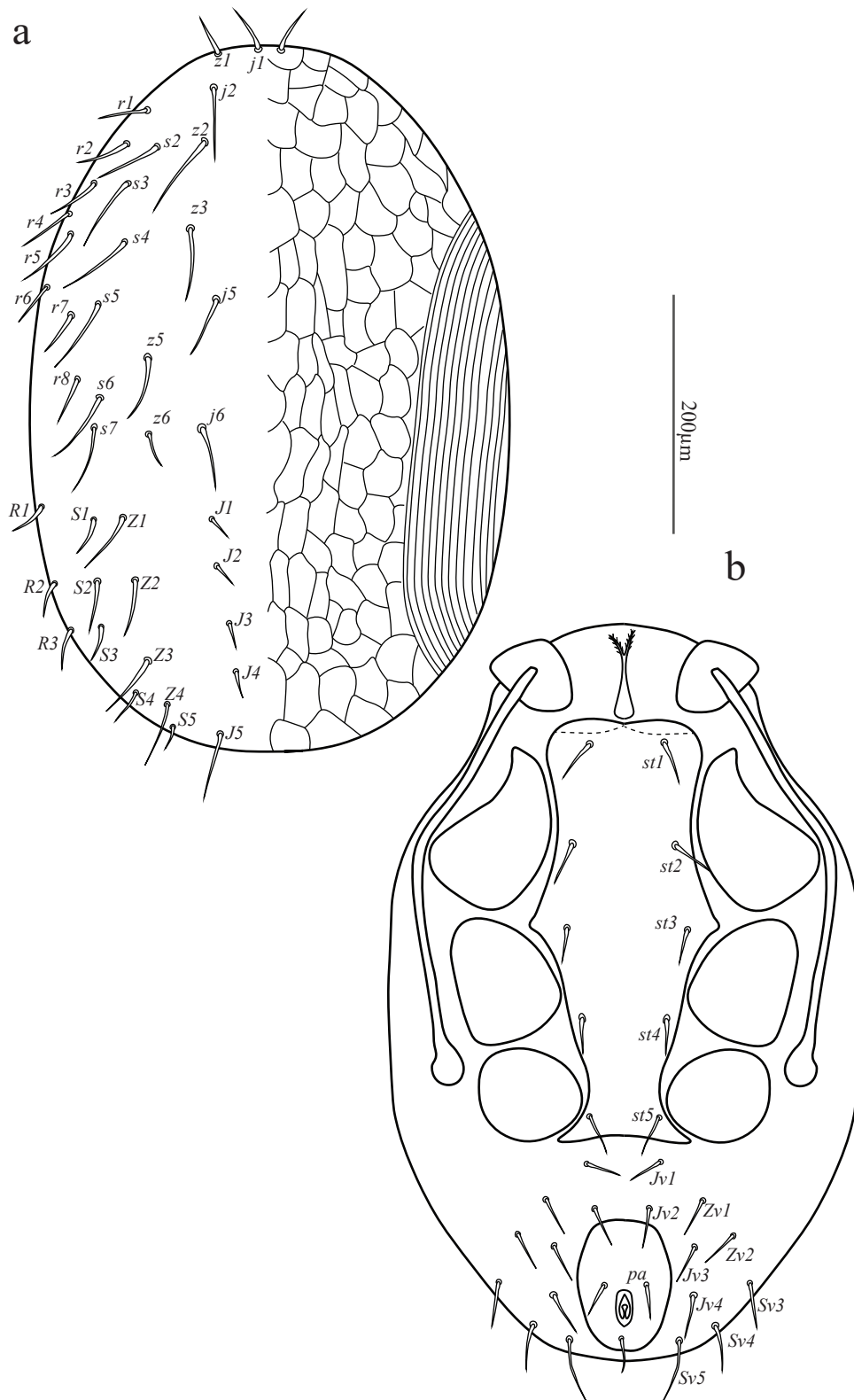


Fig. 1.93. *Laelaps* sp. Deutonymph. a.Dorsum, b.Venter.

Hypoaspis heselhousi Oudemans, 1912

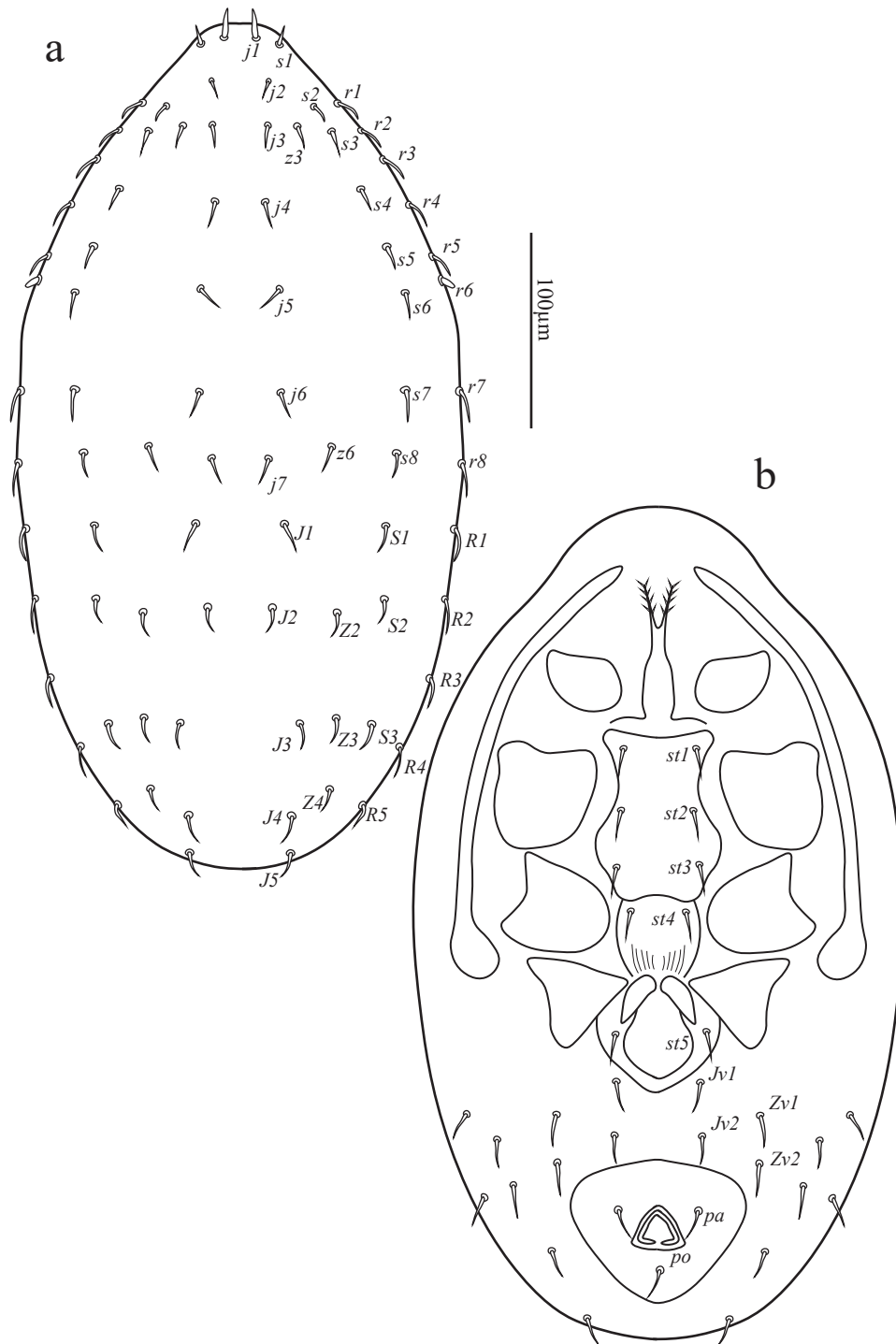


Fig. 1.94. *Hypoaspis heselhousi* Adult female. a.Dorsum, b.Venter

Hypoaspis sardous (Canestrini, 1884)

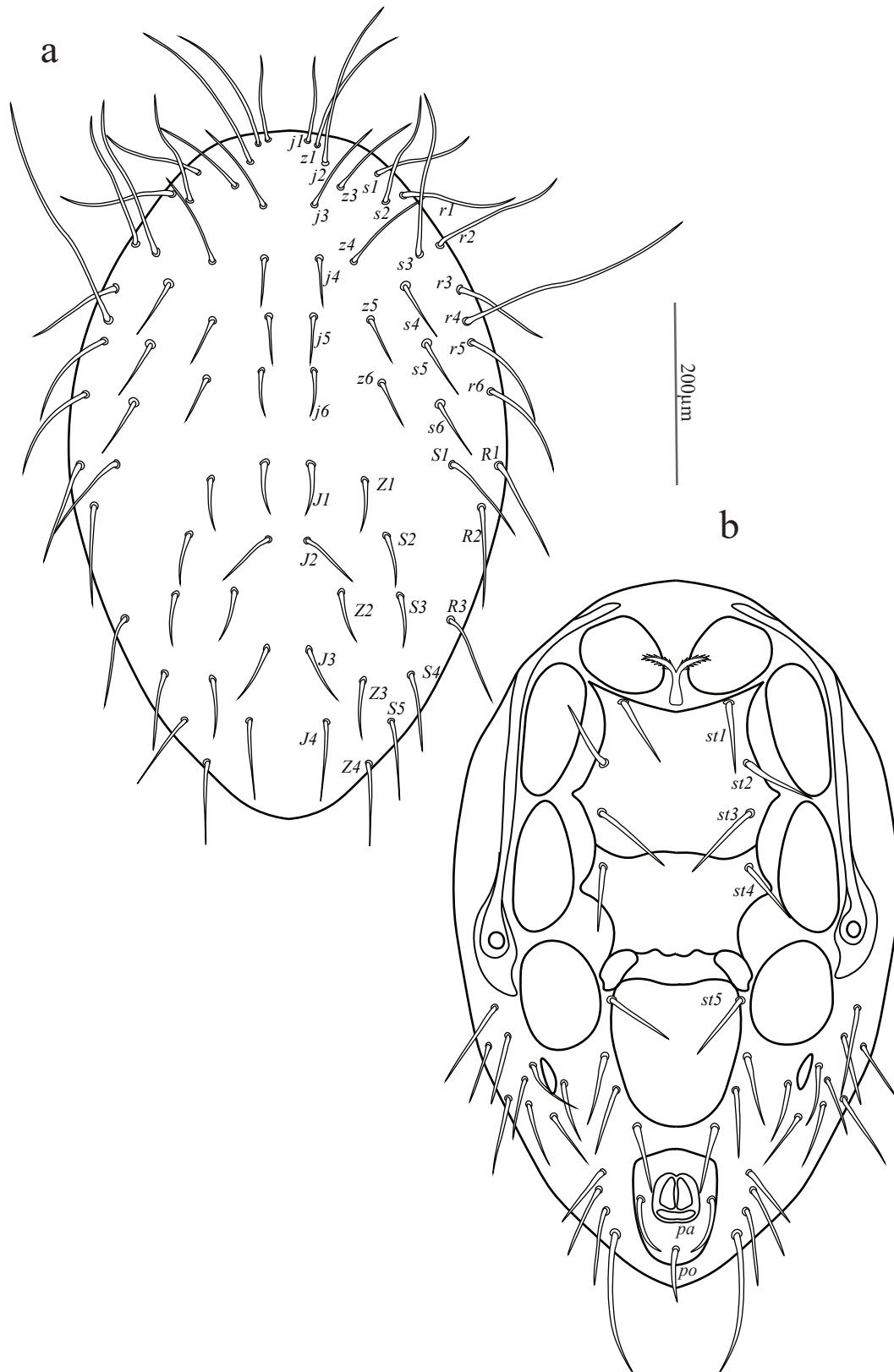


Fig. 1.95. *Hypoaspis sardous* Adult female a.Dorsum,b.Venter

Hypoaspis subterranea Willman, 1952

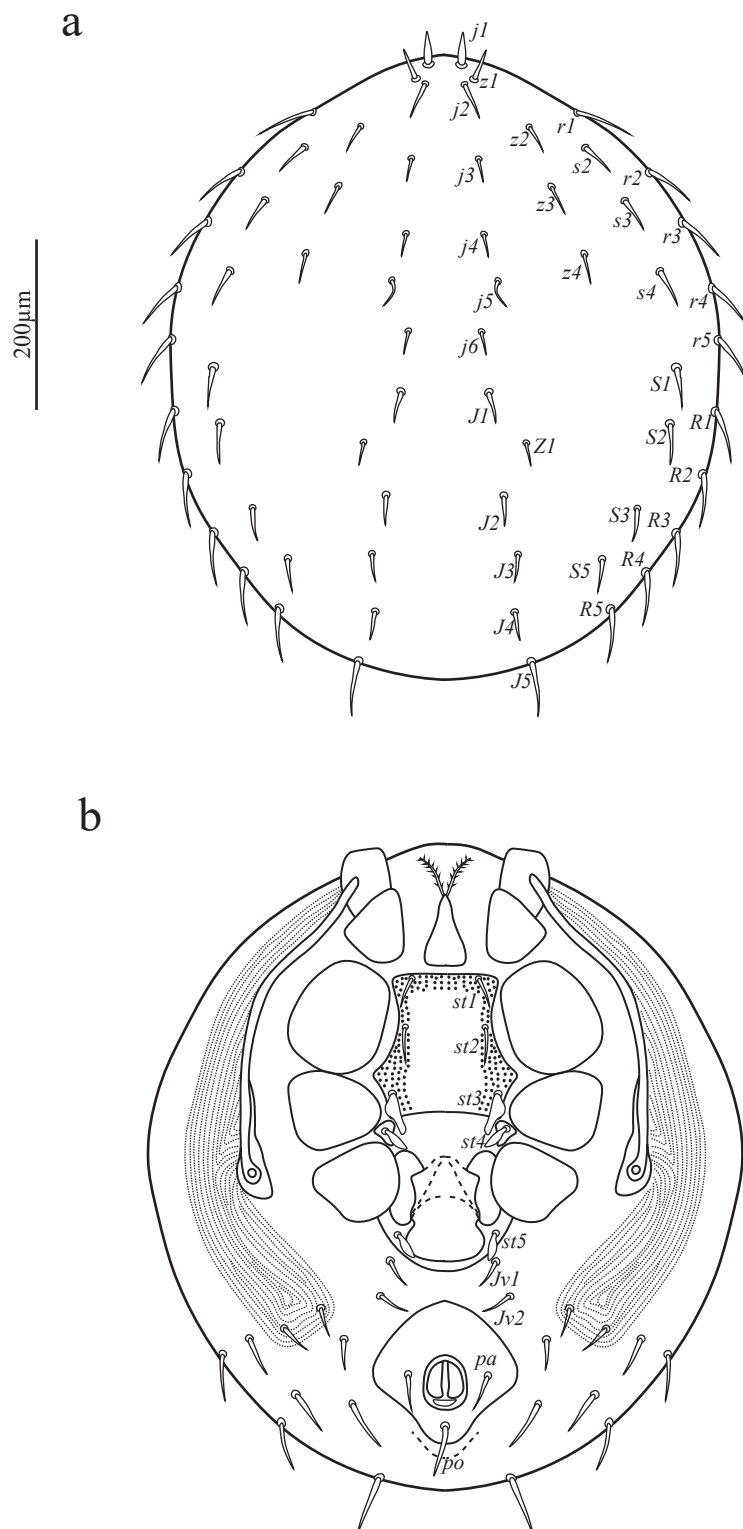


Fig. 1.96. *Hypoaspis subterranea* Adult female a.Dorsum, b.Venter

Dinogamasus sp.

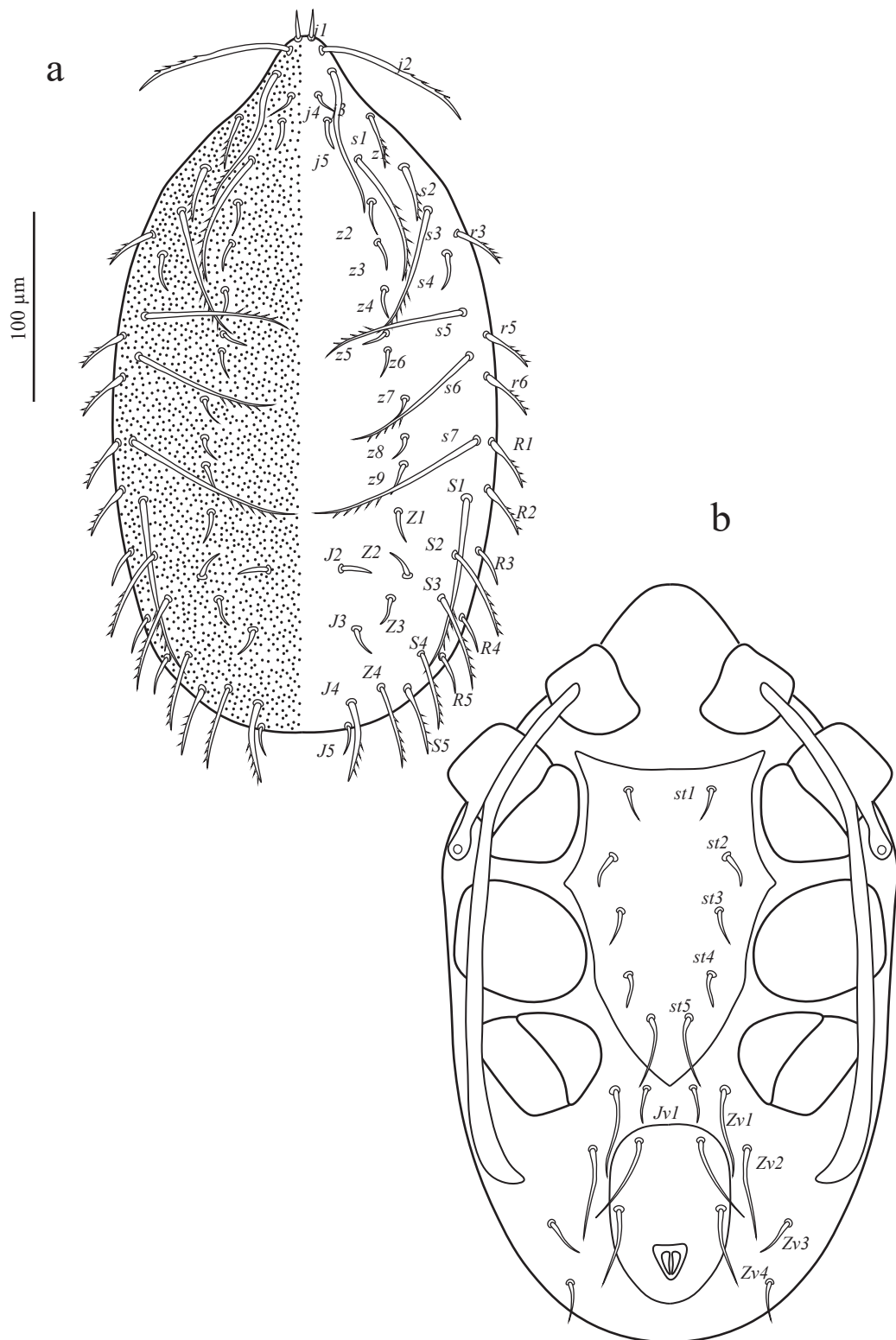


Fig. 1.97. *Dinogamasus* sp. Deutonymph. a.Dorsal, b.Venter

Cunaxa anomala Khaustov & Kuznetsov, 1998

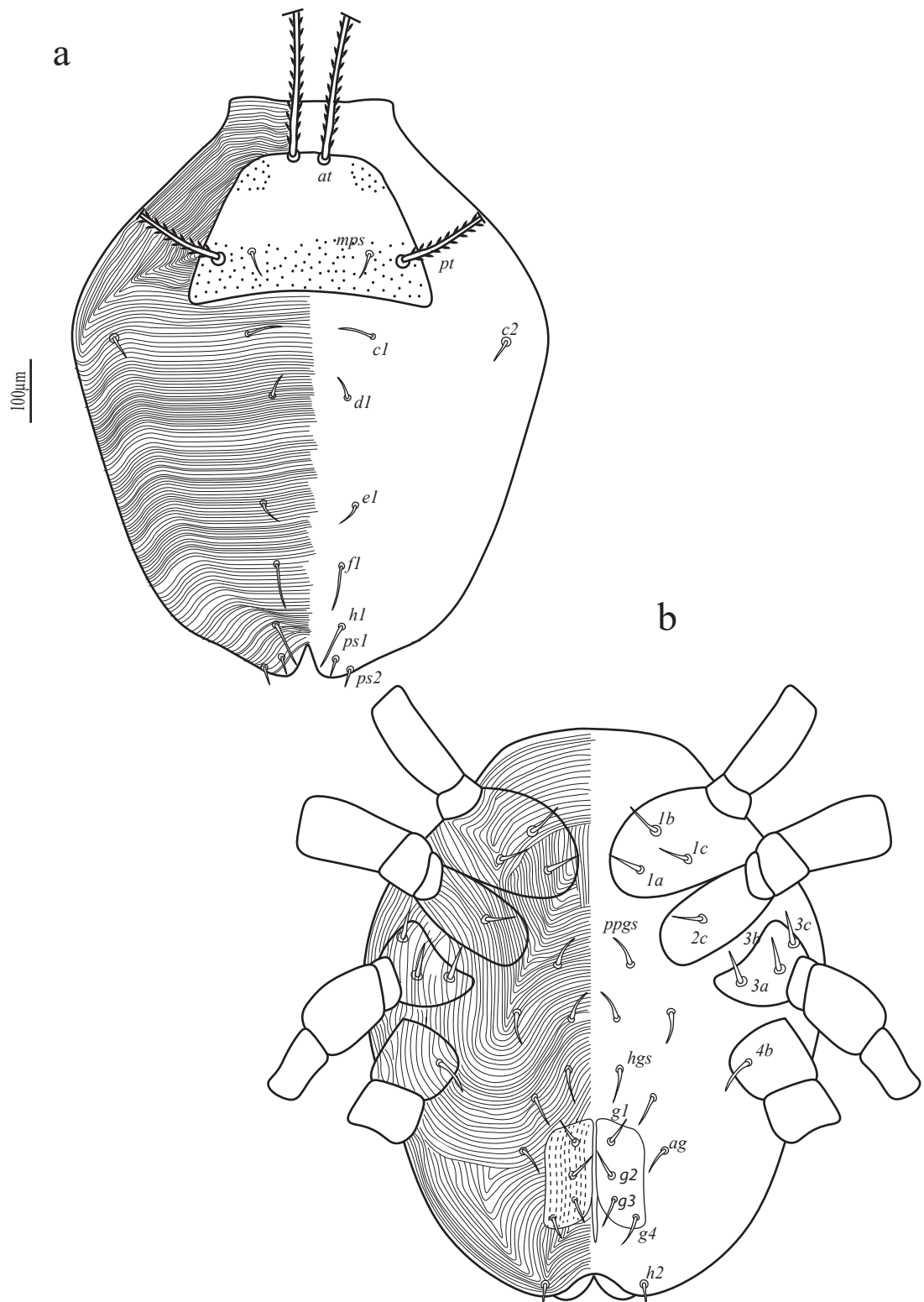


Fig. 1.98. *Cunaxa anomala* Adult female a.Dorsum, b.Venter

Cunaxa heterostriata Khaustov & Kuznetsov, 1998

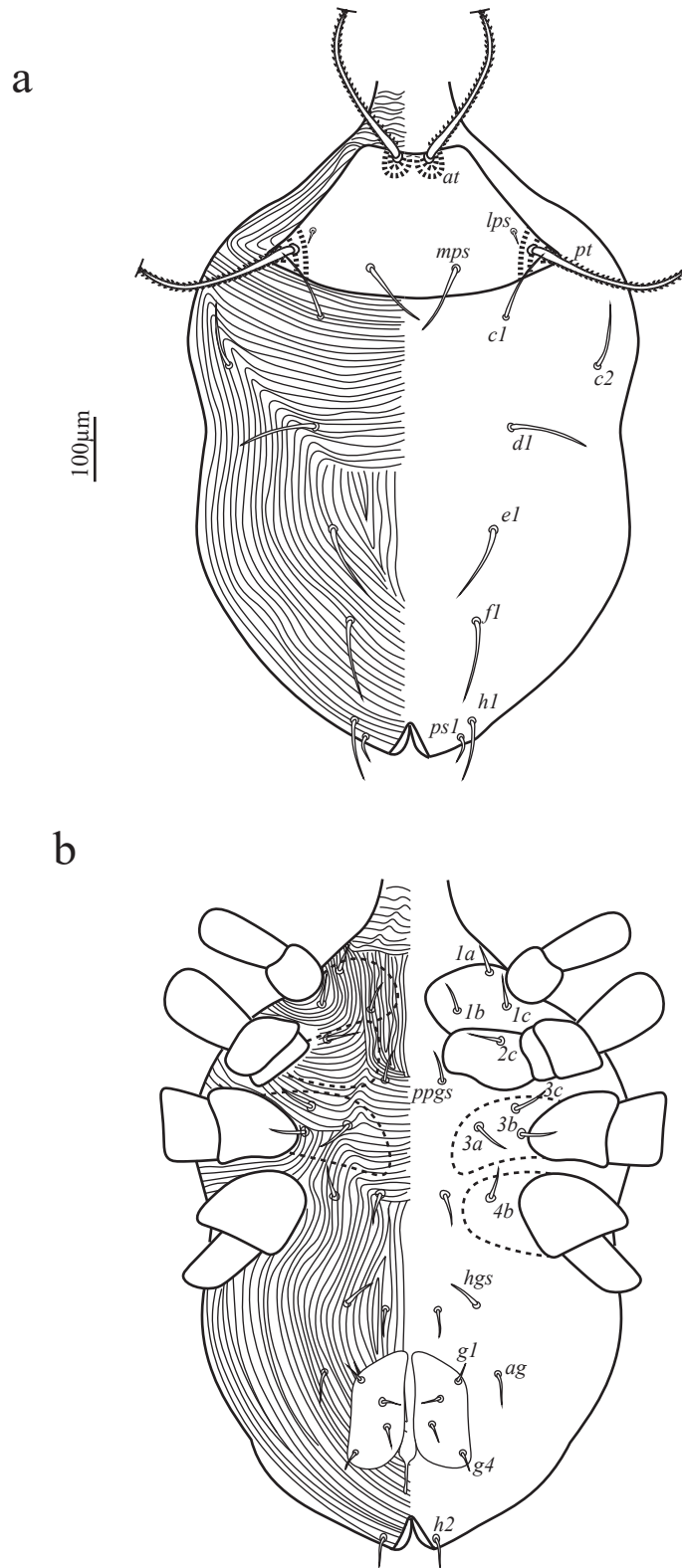


Fig. 1.99. *Cunaxa heterostriata* Adult female a. Dorsum, b.Venter

Leptus treati Welbourn and Jennings, 1991

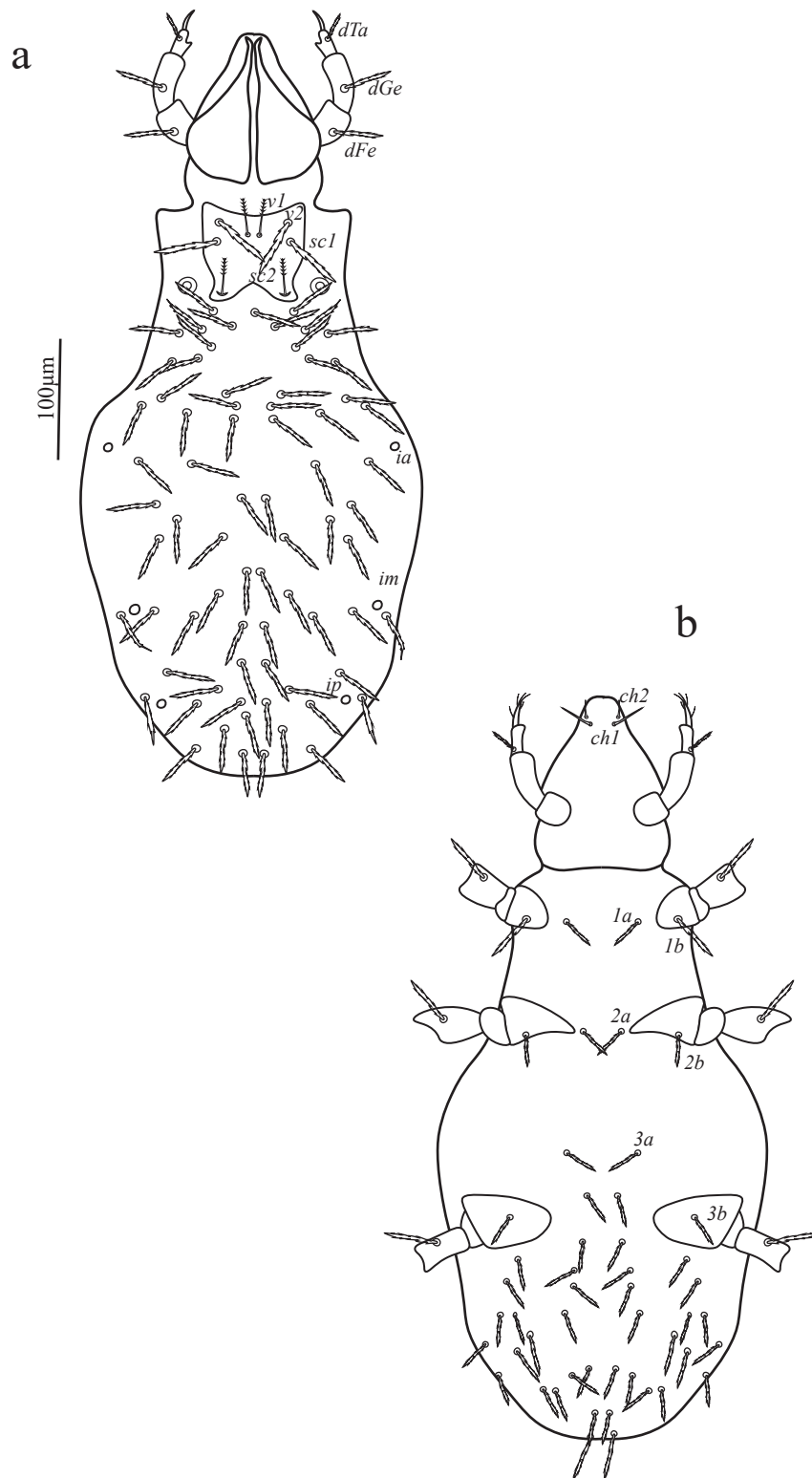


Fig. 1.100. *Leptus treati* Larva. a.Dorsum, b.Venter

Neosilphitrombium gratum Fain, 1992

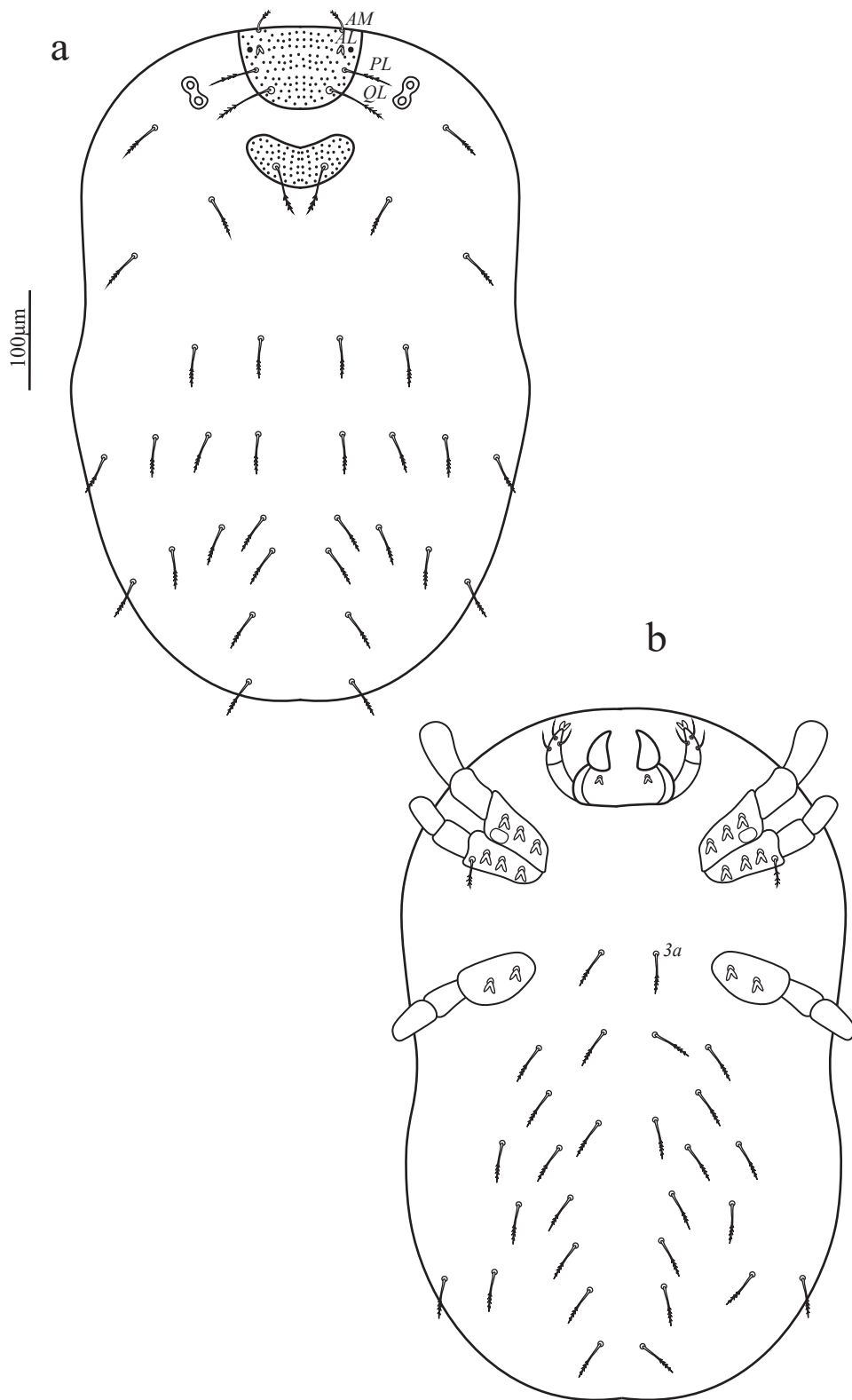


Fig. 101. *Neosilphitrombium gratum* Larva. a.Dorsum, b.Venter

Hoplocheylus longispinus Atyeo & Baker, 1964

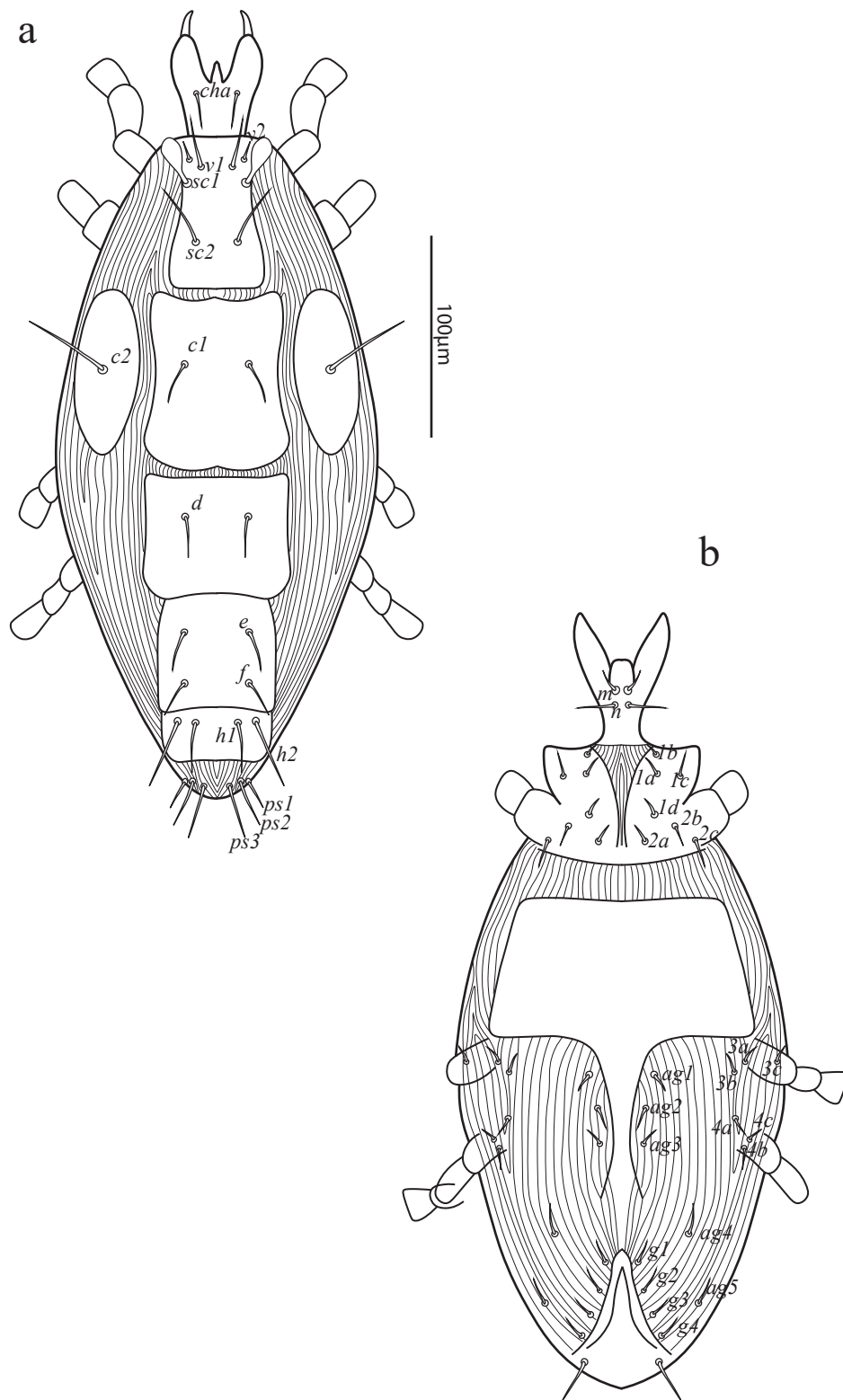


Fig. 1.103. *Hoplocheylus longispinus* Adult female a. Dorsum, b. Venter, c. Tibia and tarsus I, d. Gnathosoma

Hoplocheylus zanzibariensis Khaustov & Ermilov, 2018

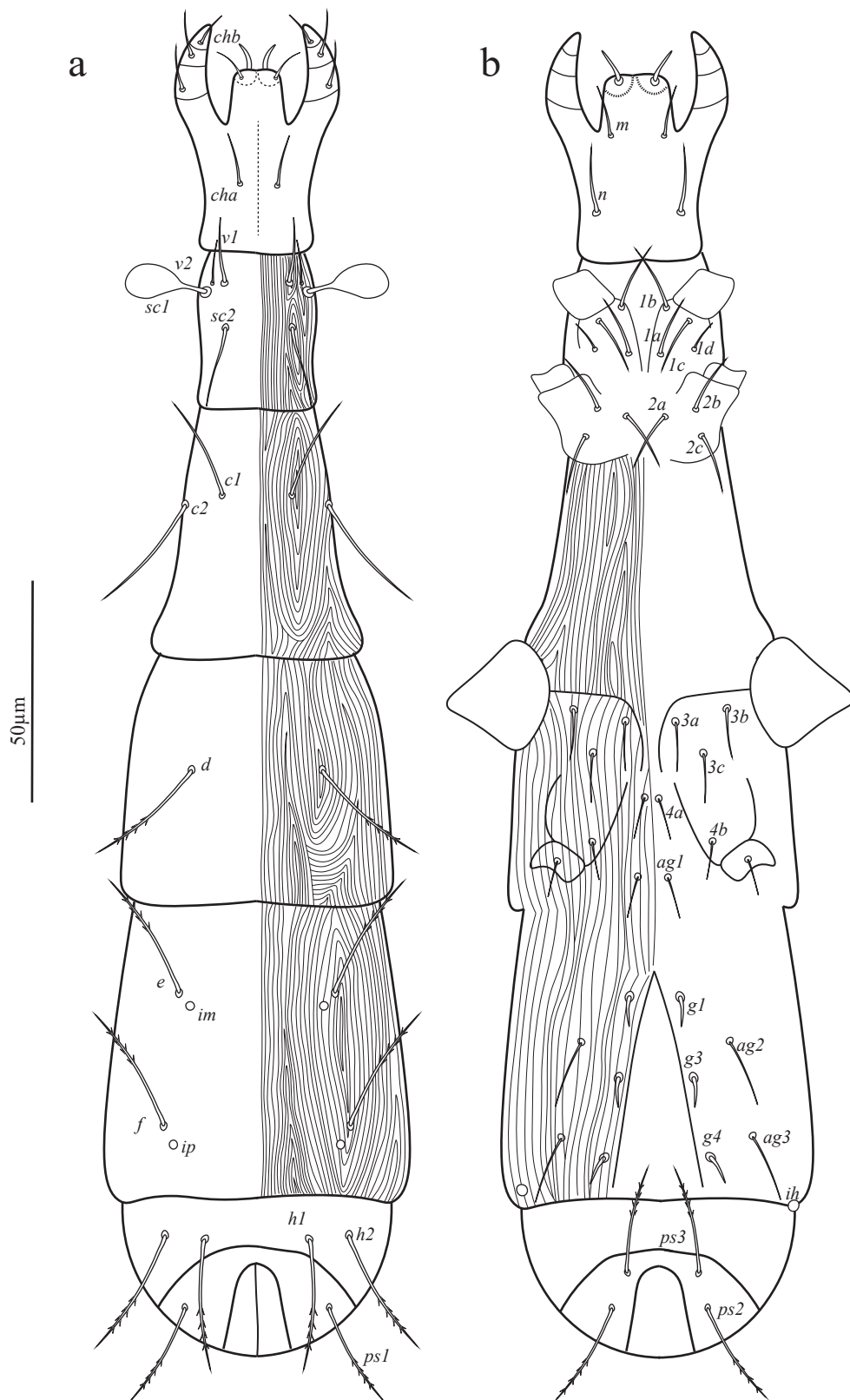


Fig. 1.104. *Hoplocheylus zanzibariensis* Adult female. a.Dorsum, b.Venter

Pavania foliata Khaustov and Frolov, 2020

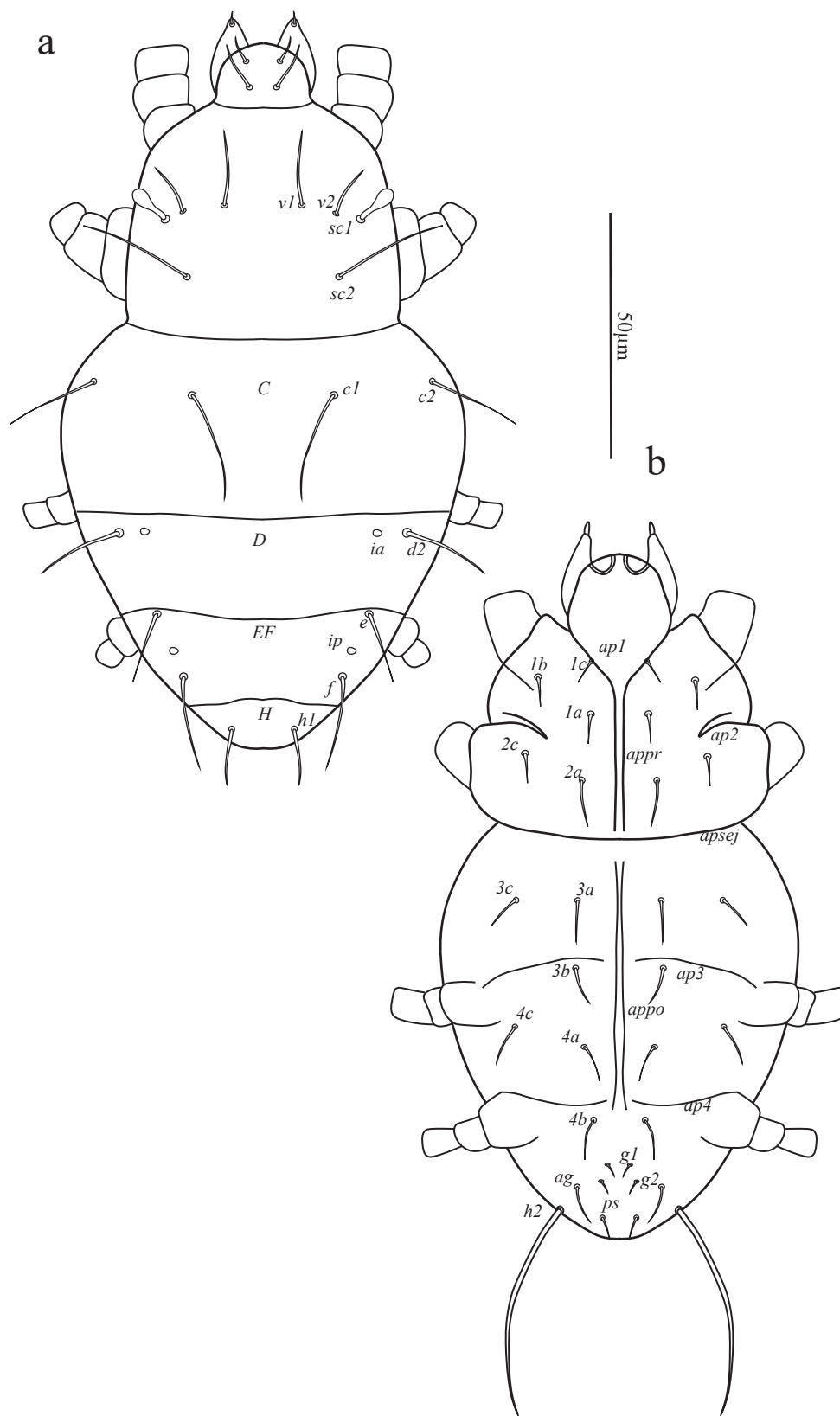


Fig. 1.105. *Pavania foliata* Adult female a.Dorsum, b.Venter

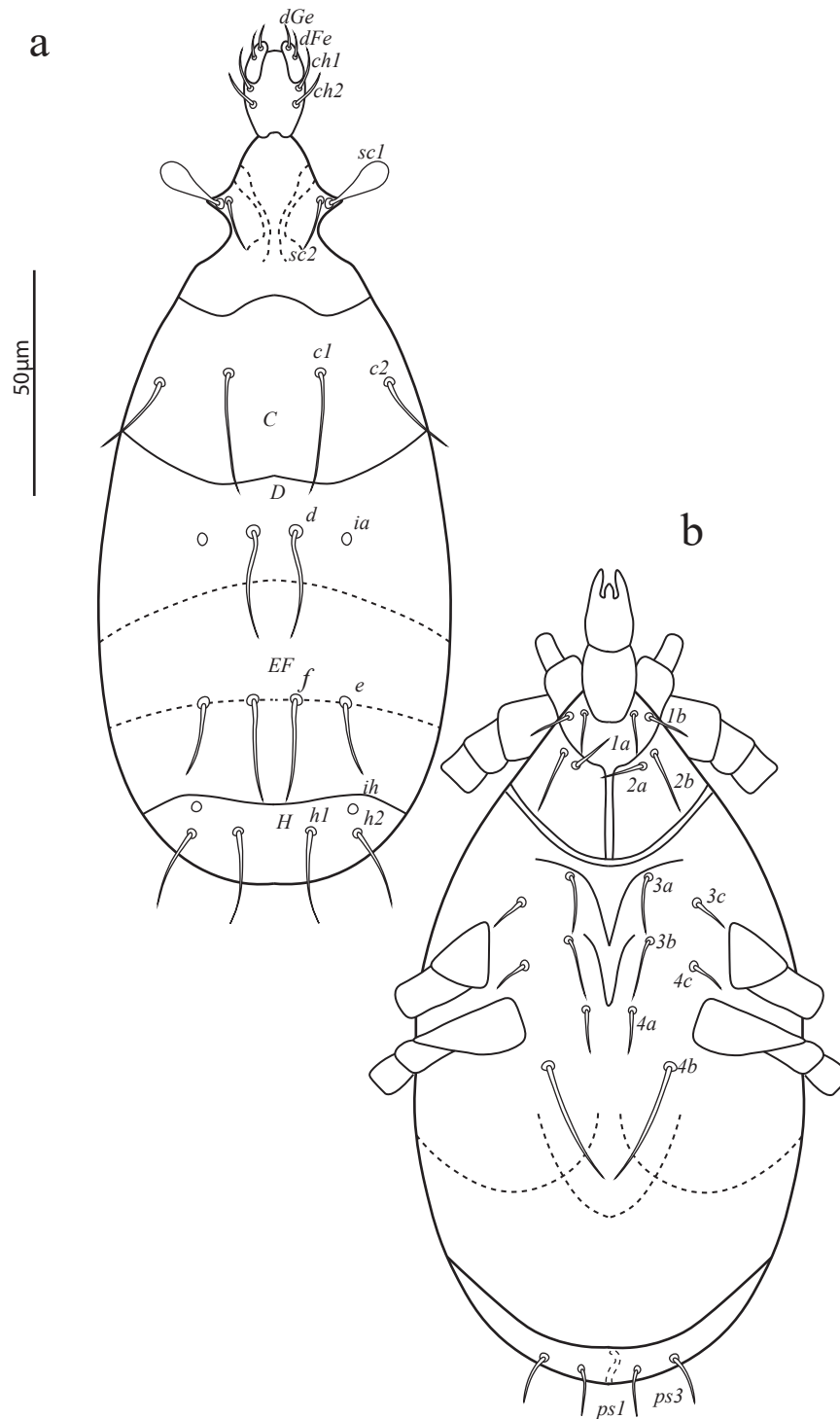


Fig. 1.106. *Premicrodispus paramaevi* Adult female. a.Dorsum, b.Venter

Pygmephorellus indicus sp. nov.

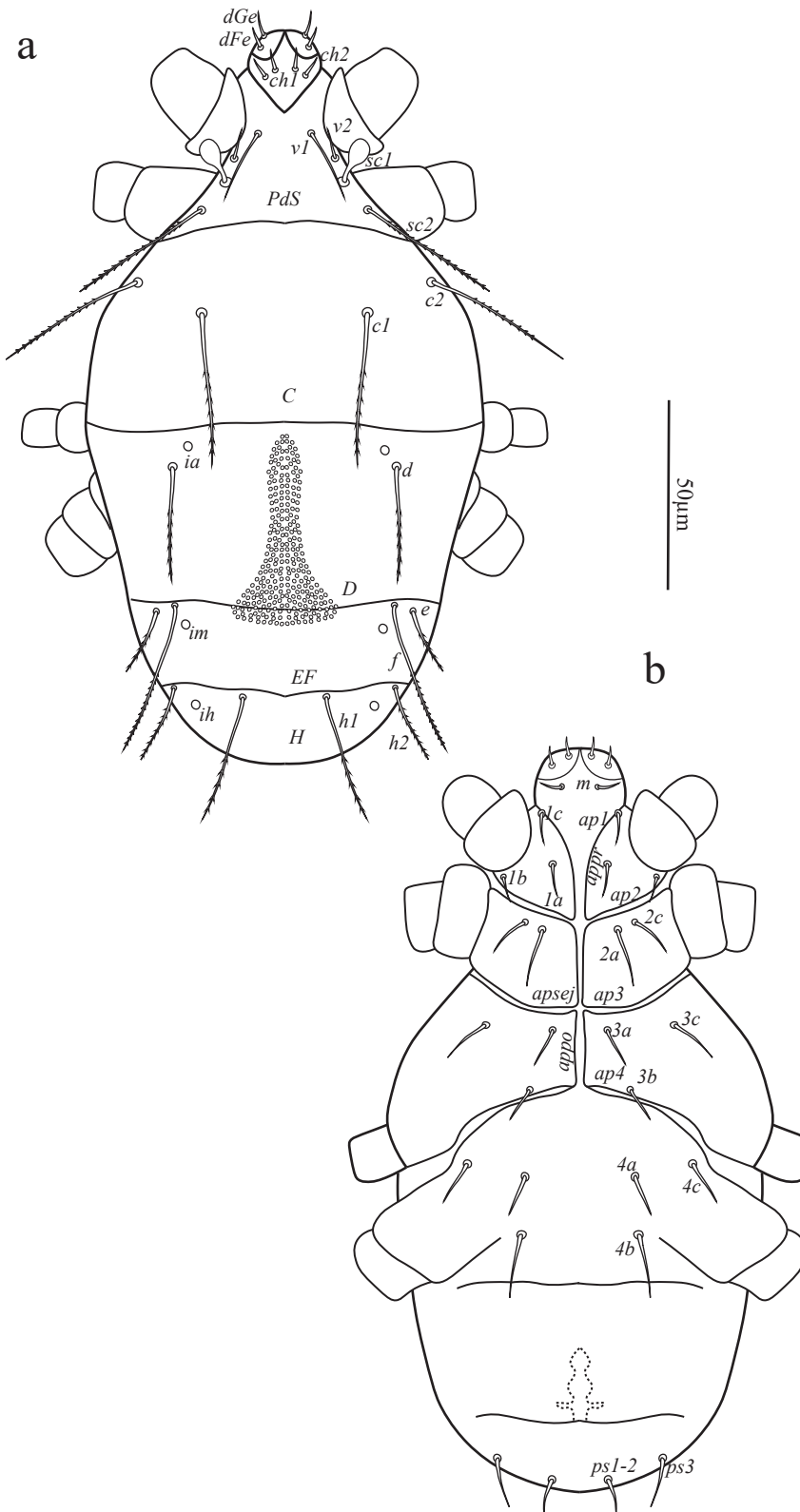


Fig. 1.107. *Pygmephorellus indicus* sp. nov. Adult female a.Dorsum, b.Venter

Pygmephorellus indicus sp. nov.

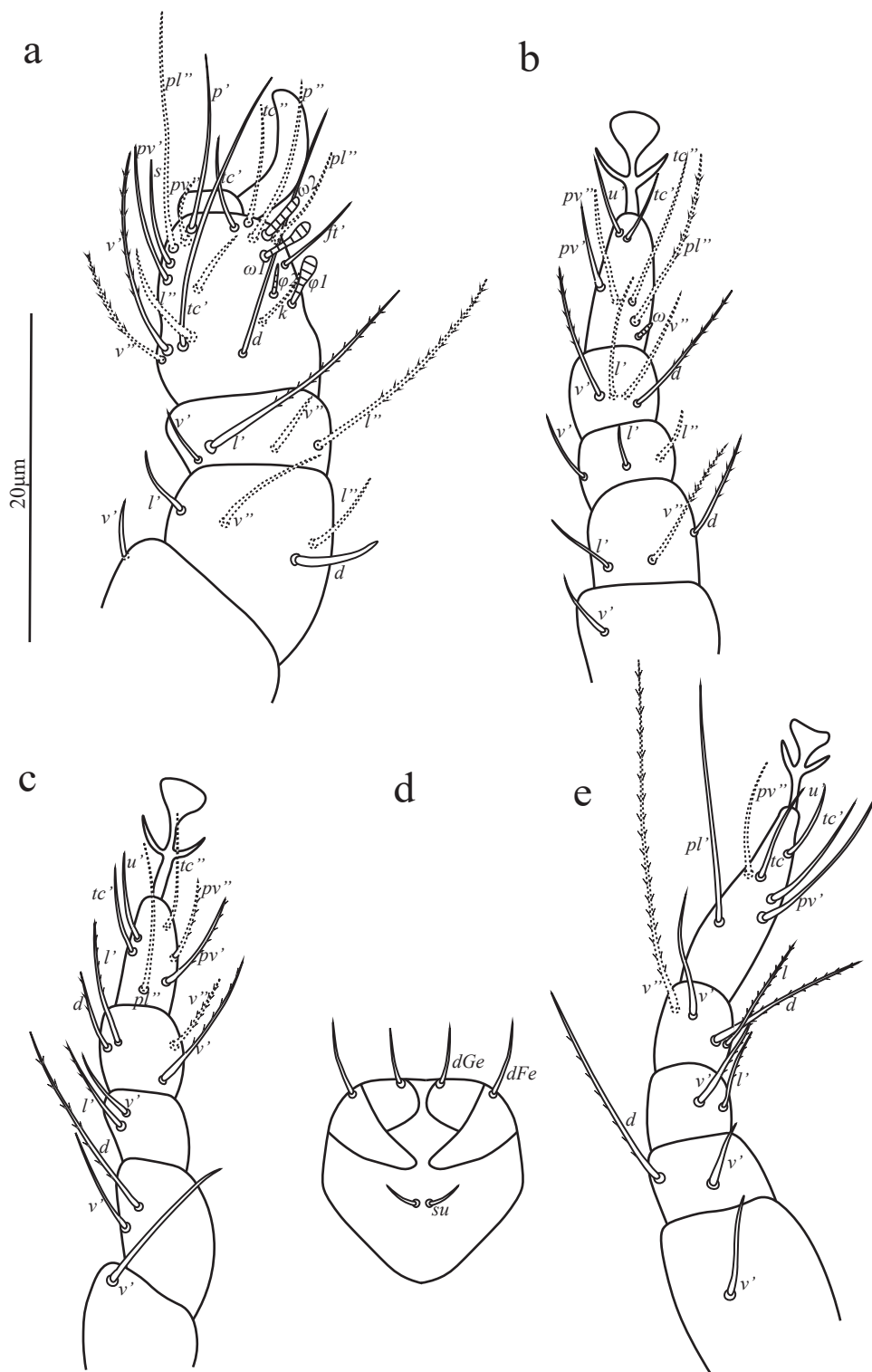


Fig. 1.108. *Pygmephorellus indicus* sp. nov. a.Leg I, b.Leg II, c.Leg III, d.Gnathosoma, e.Leg IV

a



Fig.1.109. *Steneotarsonemus brasiliensis* Adult female. a. Dorsum, b.Venter

Podapolipus palappuramensis sp. nov.

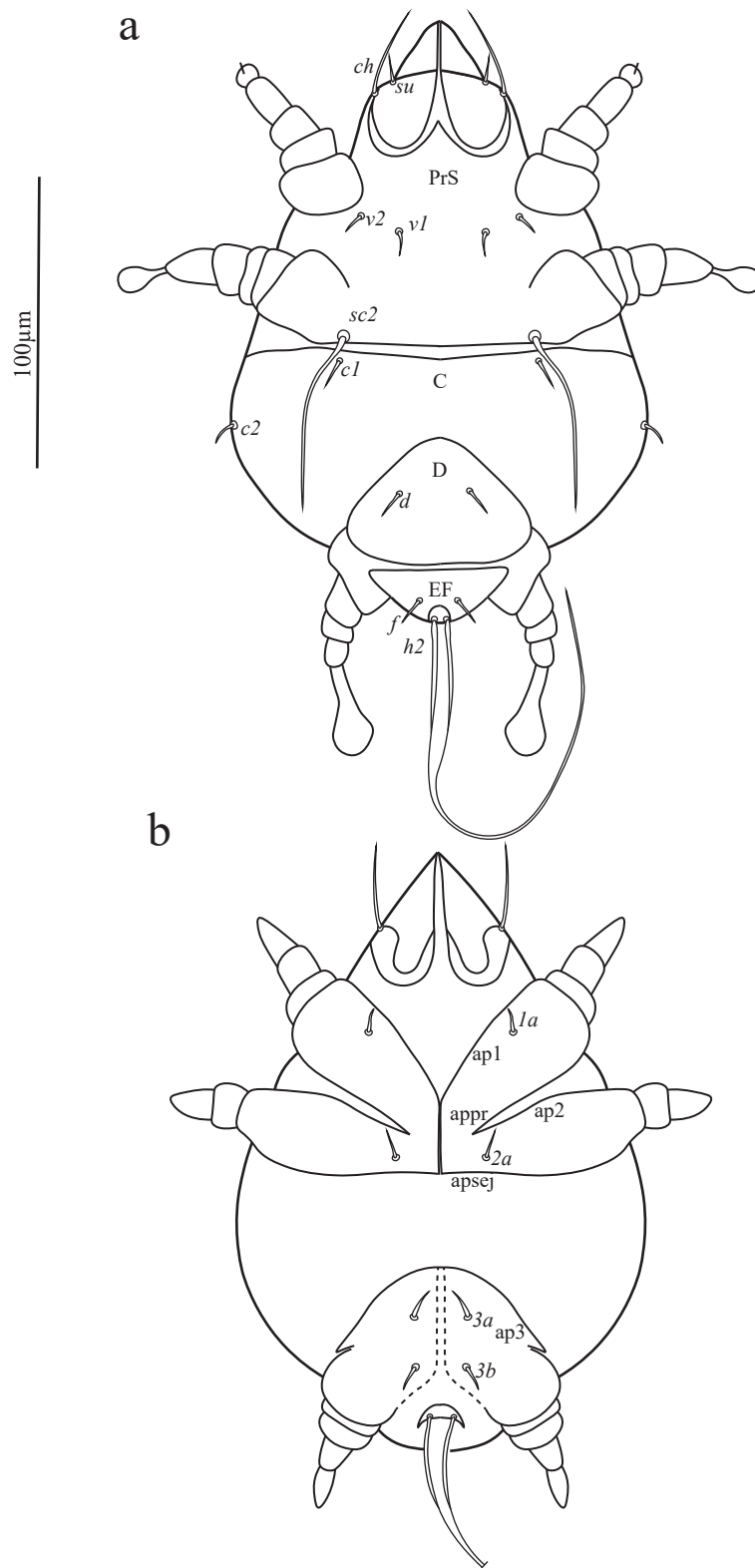


Fig. 1.110. *Podapolipus palappuramensis* sp. nov. Larval female.
a.Dorsum, b.Venter

Podapolipus palappuramensis sp. nov.

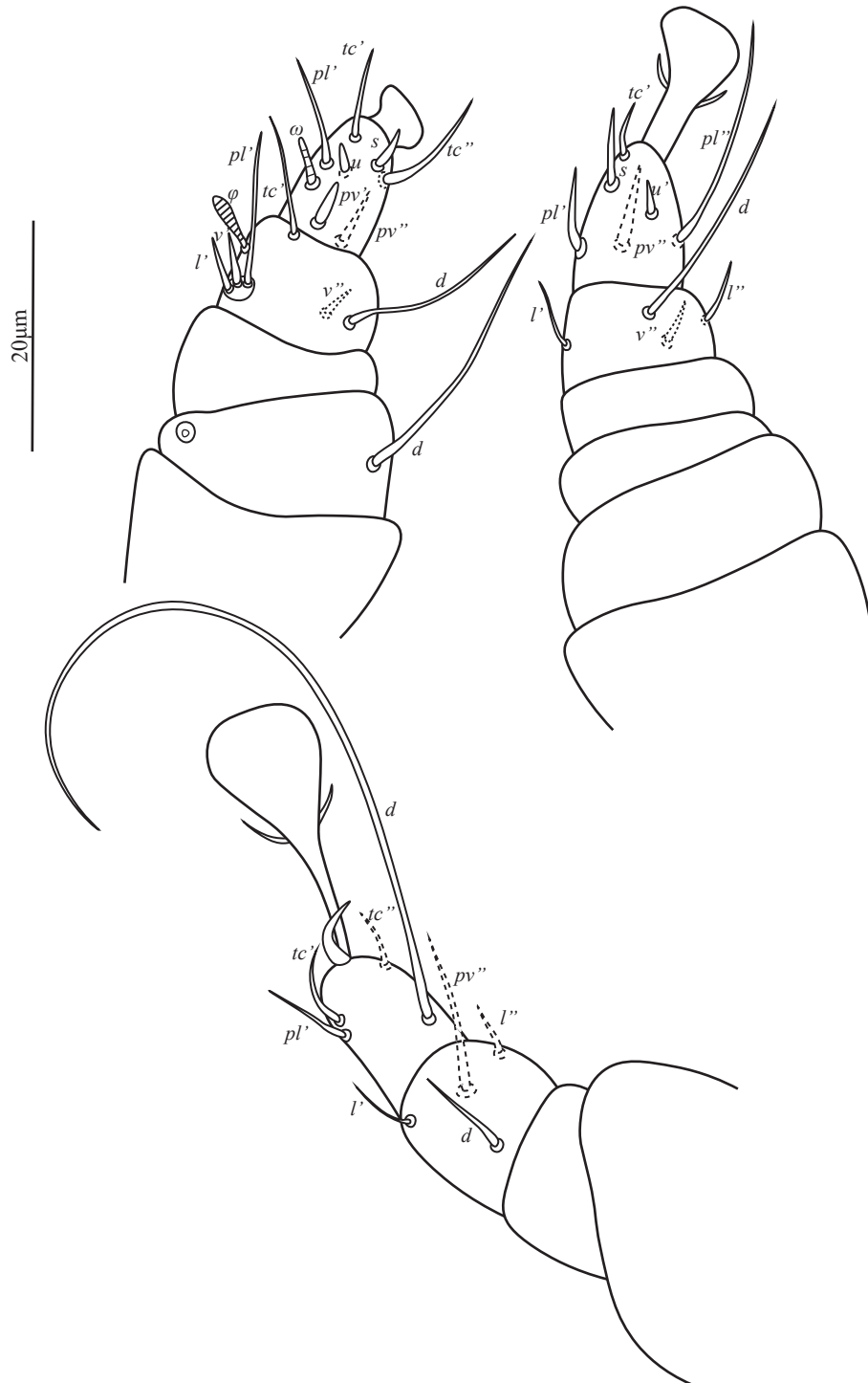


Fig. 1.111. *Podapolipus palappuramensis* sp. nov. Larval female.
a.Leg I, b.Leg II, c.Leg III.

Podapolipus palappuramensis sp. nov.

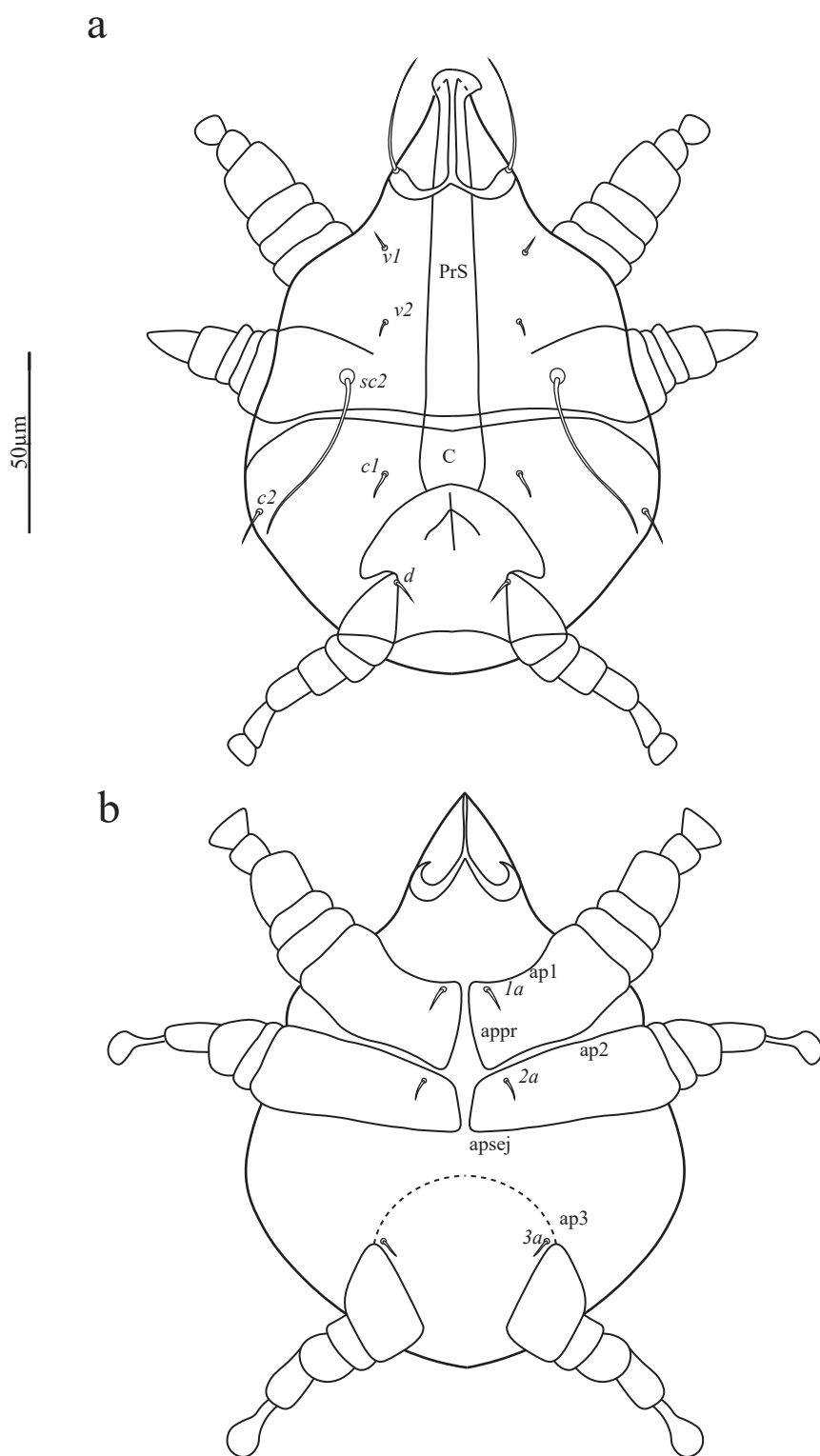


Fig. 1.112. *Podapolipus palappuramensis* sp. nov. Adult male.
a.Dorsum, b.Venter

Podapolipus palappuramensis sp. nov.

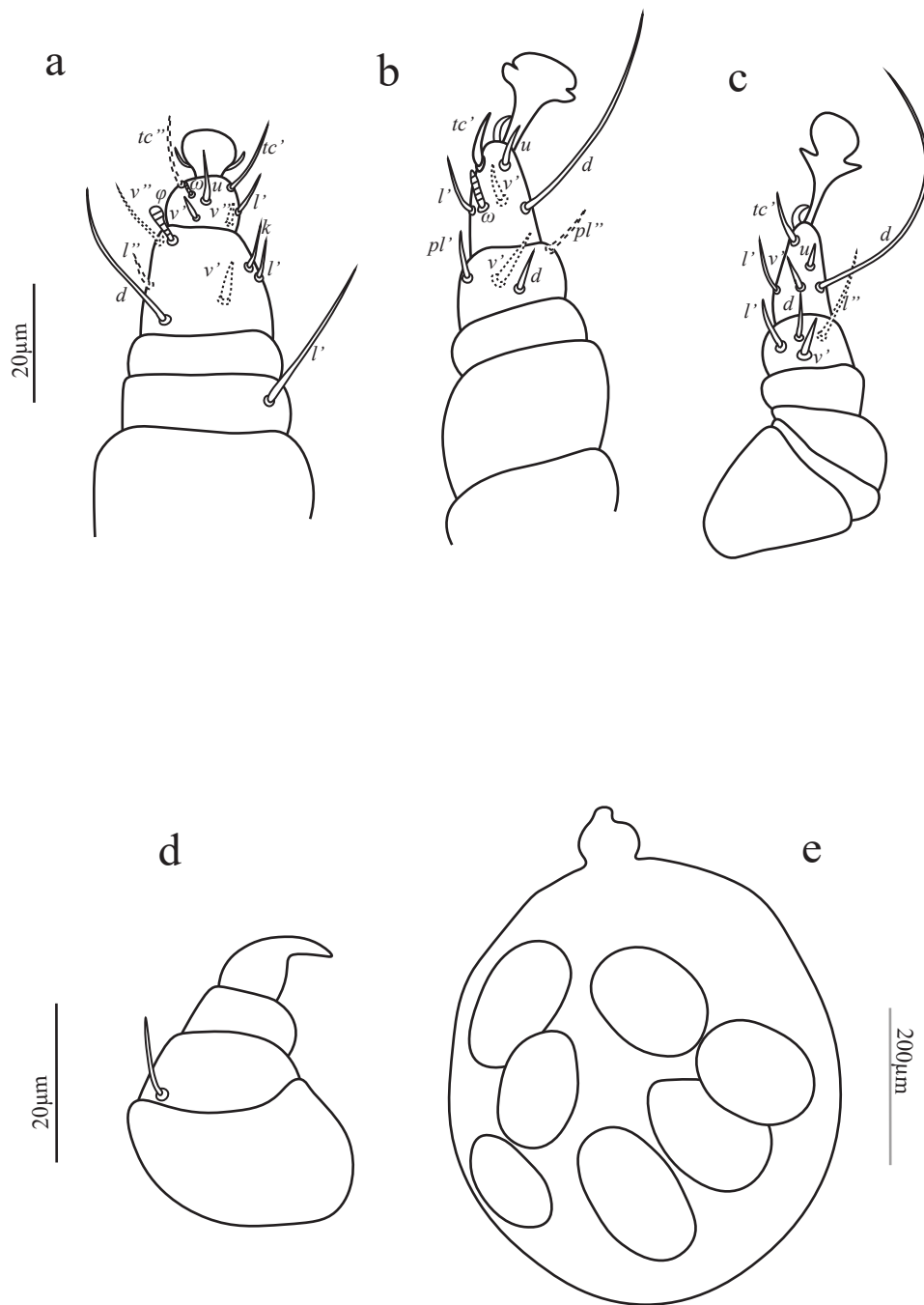


Fig. 1.113. *Podapolipus palappuramensis* sp. nov. Adult male. a.Leg I, b.Leg II, c.Leg III, d. Leg of adult female, e.Adult female.

Locustacarus chinensis sp. nov.

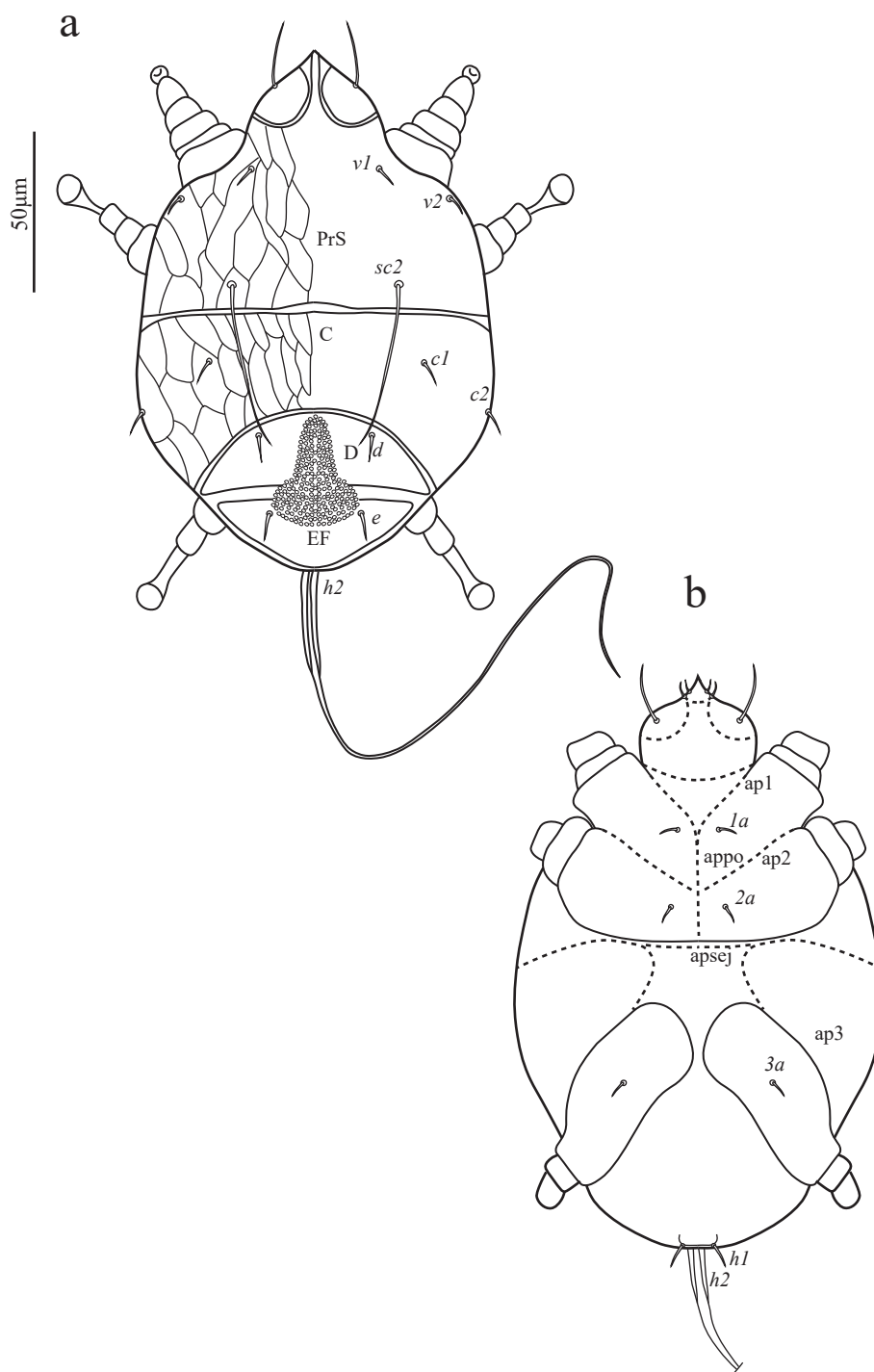


Fig. 1.115. *Locustacarus chinensis* sp. nov. Larval female a.Dorsum, b.Venter

Locustacarus chinensis sp. nov.

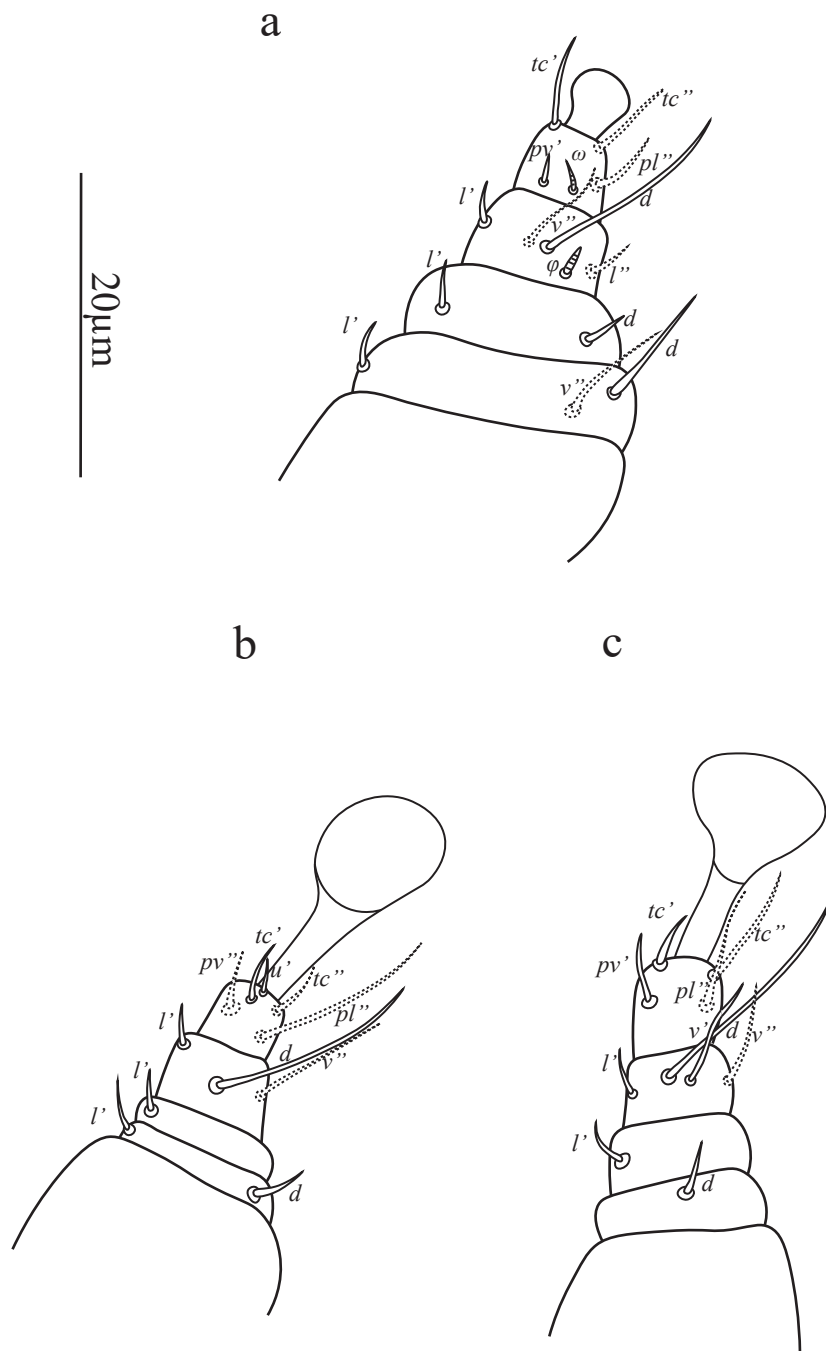


Fig. 1.116. *Locustacarus chinensis* sp. nov. Larval female. a. Leg I, b. Leg II, c. Leg III

Histiostoma furrowa sp. nov.

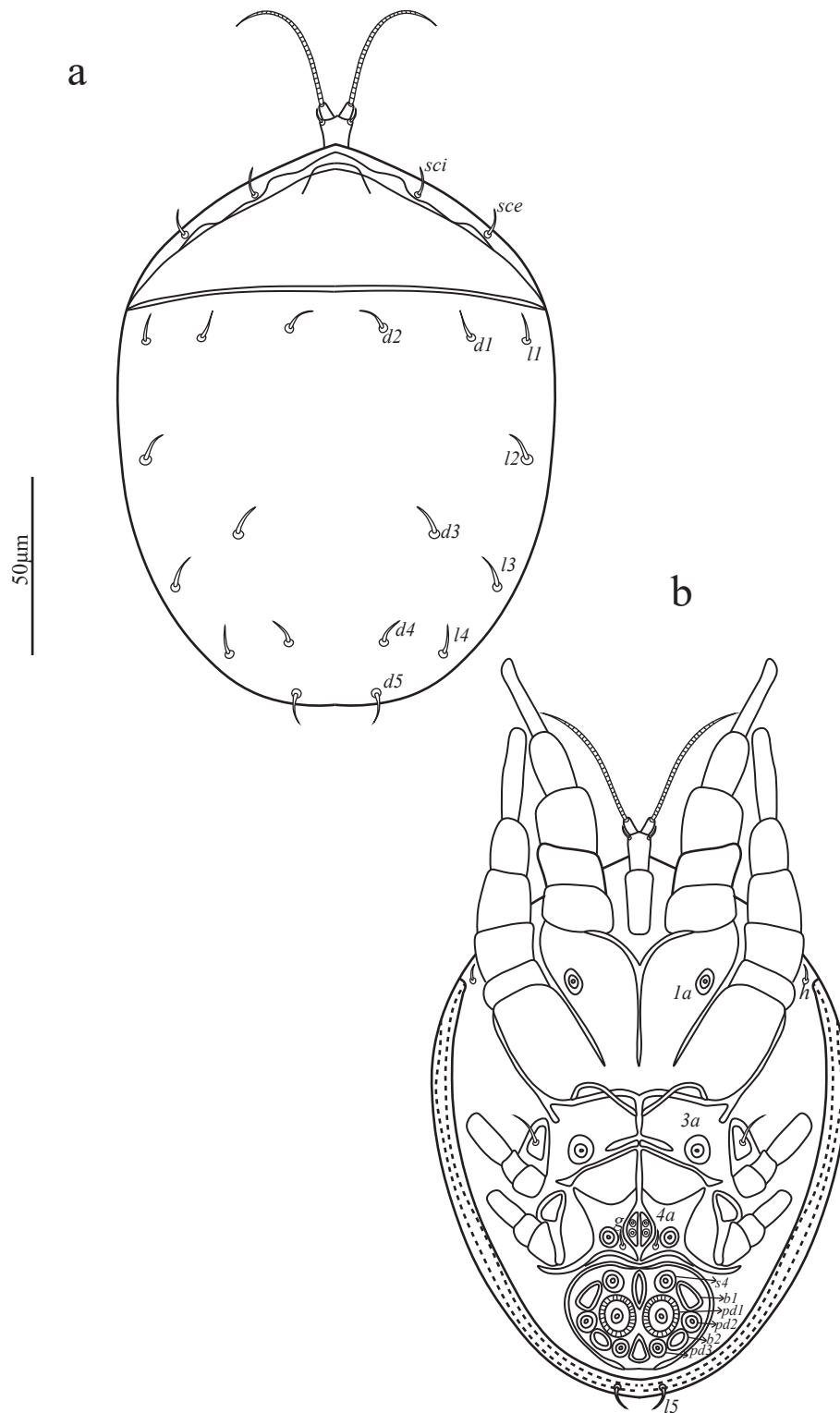


Fig. 1.117. *Histiostoma furrowa* sp. nov. Deutonymph a.Dorsum, b.Venter

Histiostoma furrowa sp. nov.

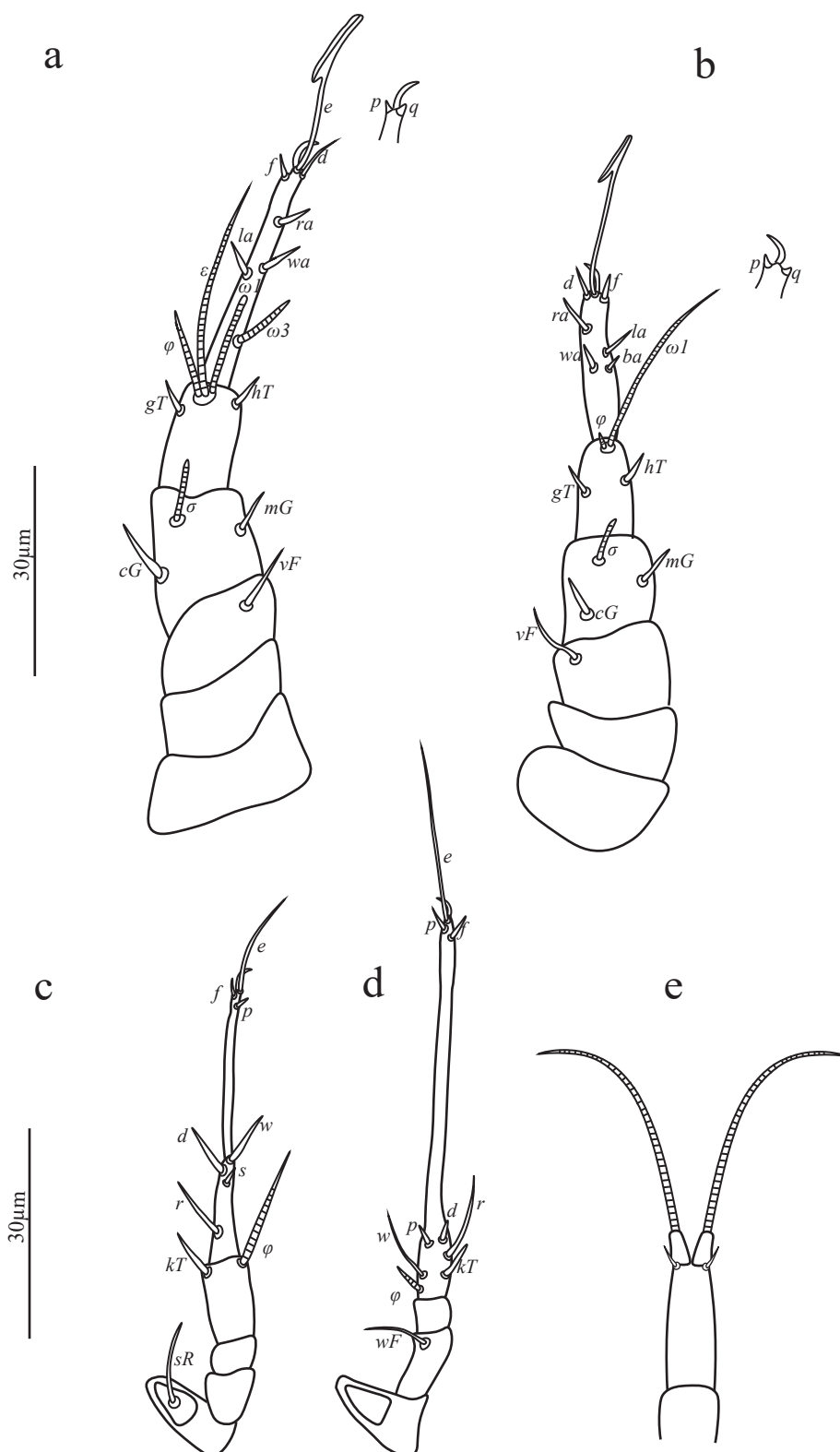


Fig. 1.118. *Histiostoma furrowa* sp. nov. Deutonymph a. Leg I, b. Leg II, c. Leg III, d. Leg IV, e. Gnathosoma.

Histiostoma herballi Eraky, 2017

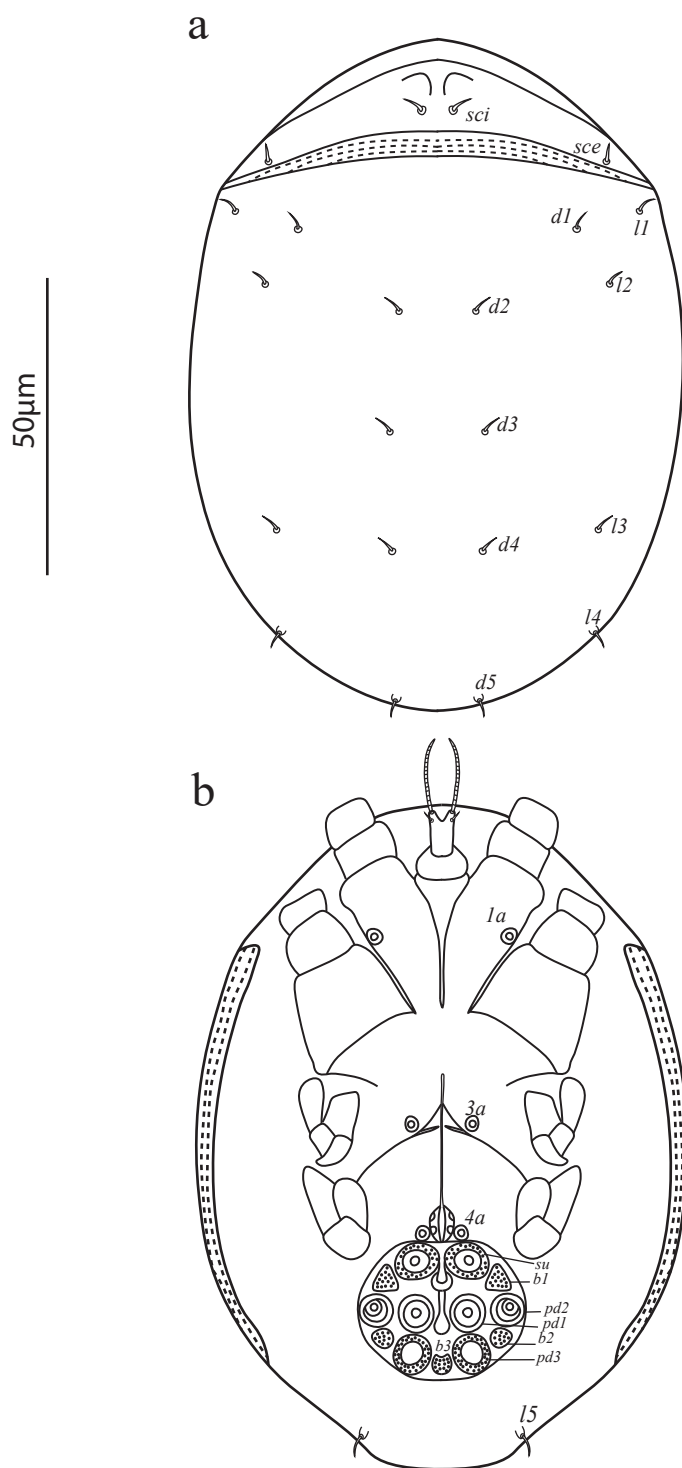


Fig.1.119. *Histiostoma herballi* Deutonymph a.Dorsum, b.Venter

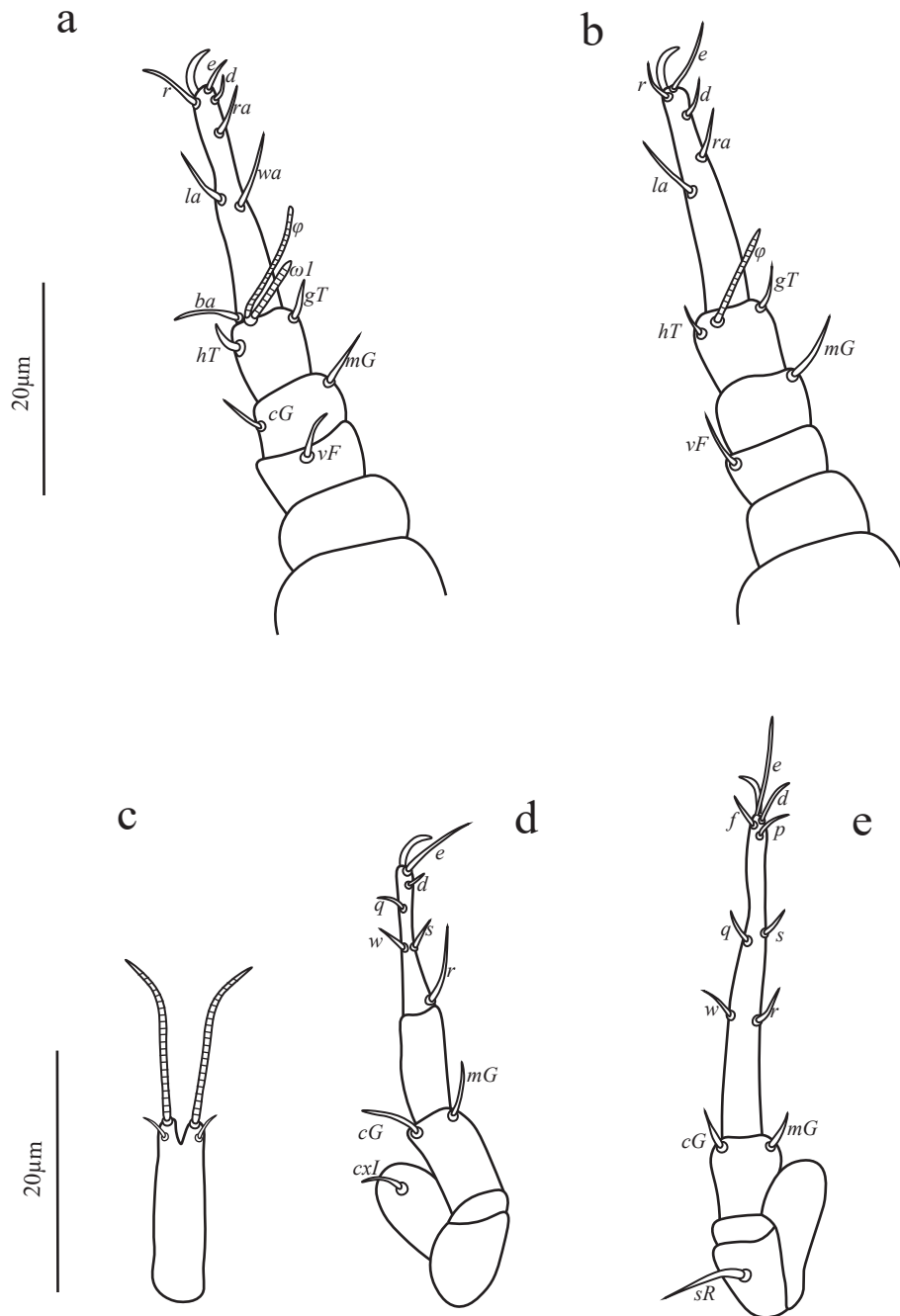


Fig. 1.120. *Histiostoma herballi* Deutonymph a. Leg I, b. Leg II, c. Gnathosoma, d. Leg IV, e. Leg V

Histiostoma maritimus (Oudemans, 1914)

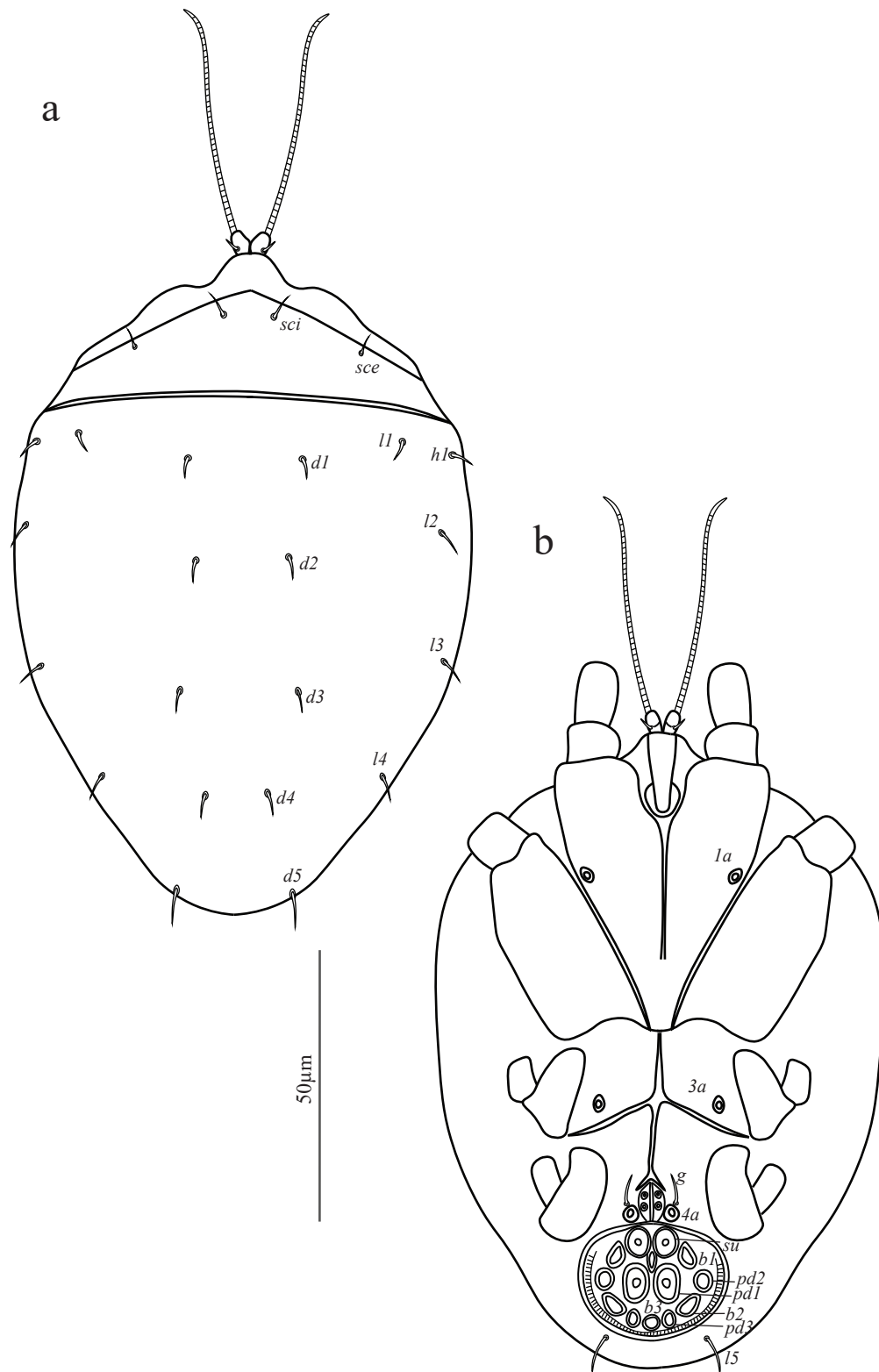


Fig. 1.121. *Histiostoma maritimus* Deutonymph a. Dorsum, b. Venter

Histiostoma maritimus (Oudemans, 1914)

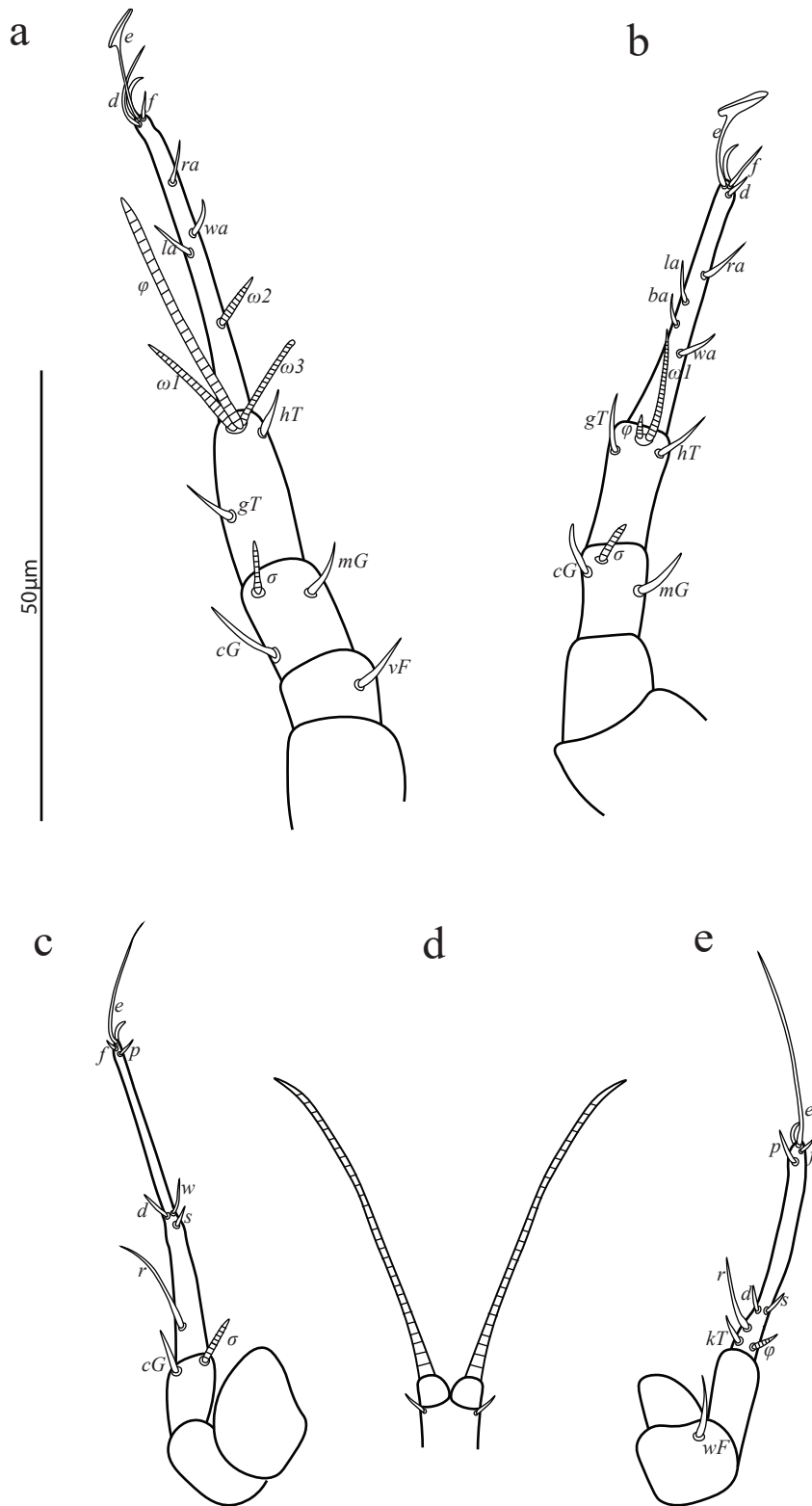


Fig. 1.122. *Histiostoma maritimus* Deutonymph a.Leg I, b.Leg II, c. Leg III, d. Gnathosoma, e.Leg IV

Histiostoma sammari Eraky, 1999

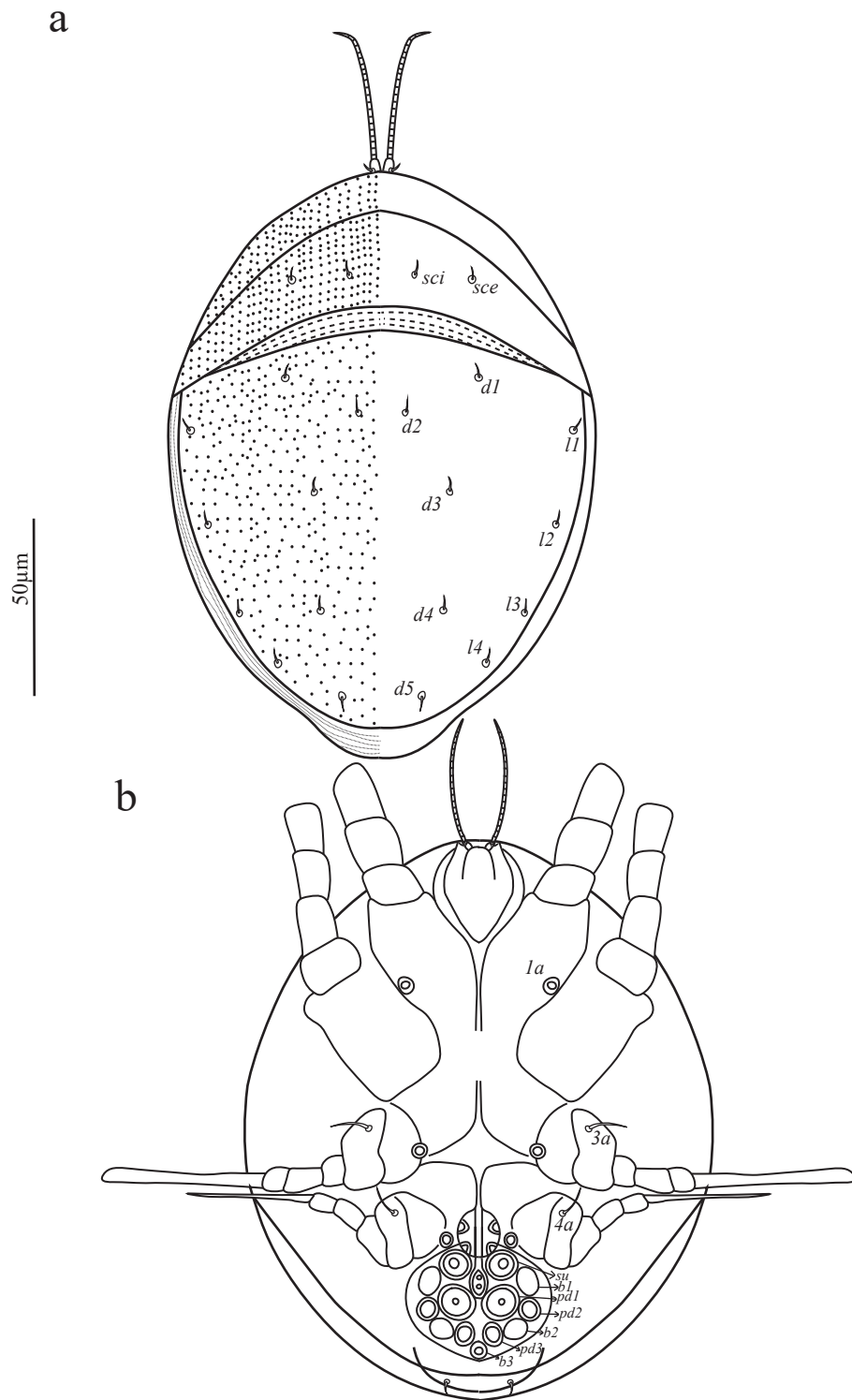


Fig. 1.123. *Histiostoma sammari* Deutonymph a.Dorsum, b.Venter

Histiostoma sammari Eraky, 1999

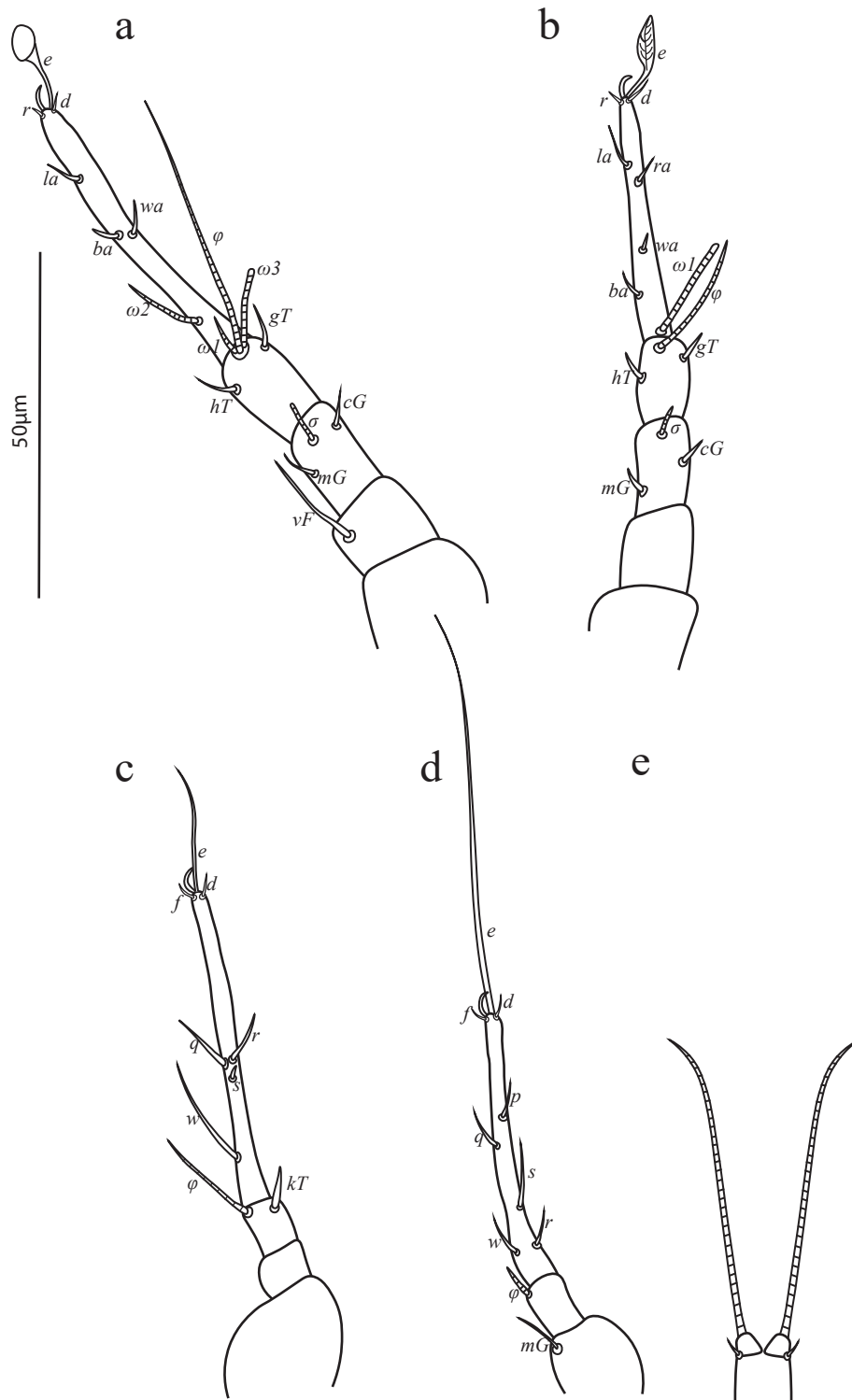


Fig. 1.124. *Histiostoma sammari* Deutonymph a.Leg I, b.Leg II, c.Leg III, d.Leg IV, e. Gnathosoma

Curculanoetus keralensis sp. nov.

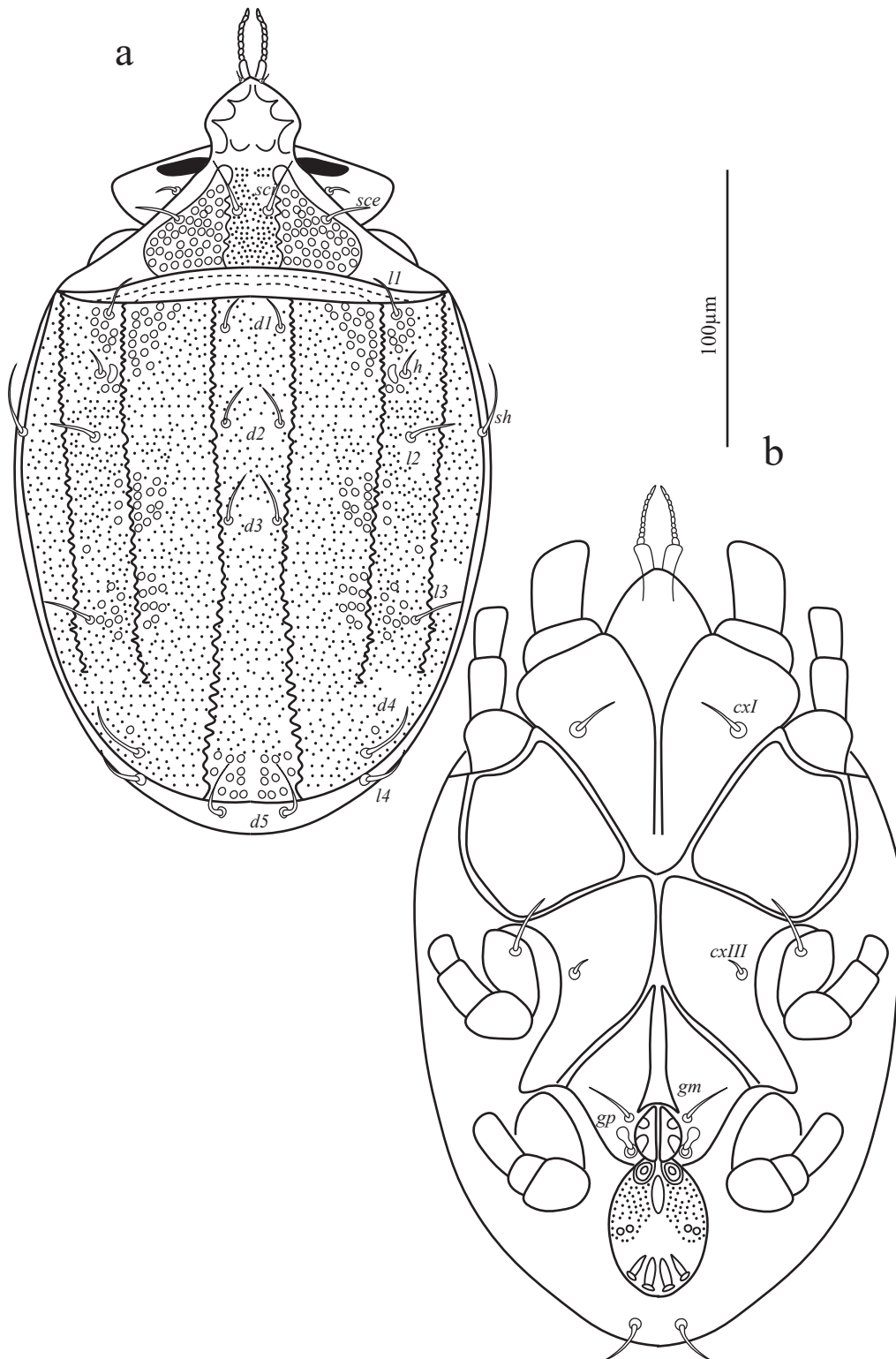


Fig. 1.125. *Curculanoetus keralensis* sp. nov. Deutonymph.
a.Dorsum, b.Venter

Curculanoetus keralensis sp. nov.

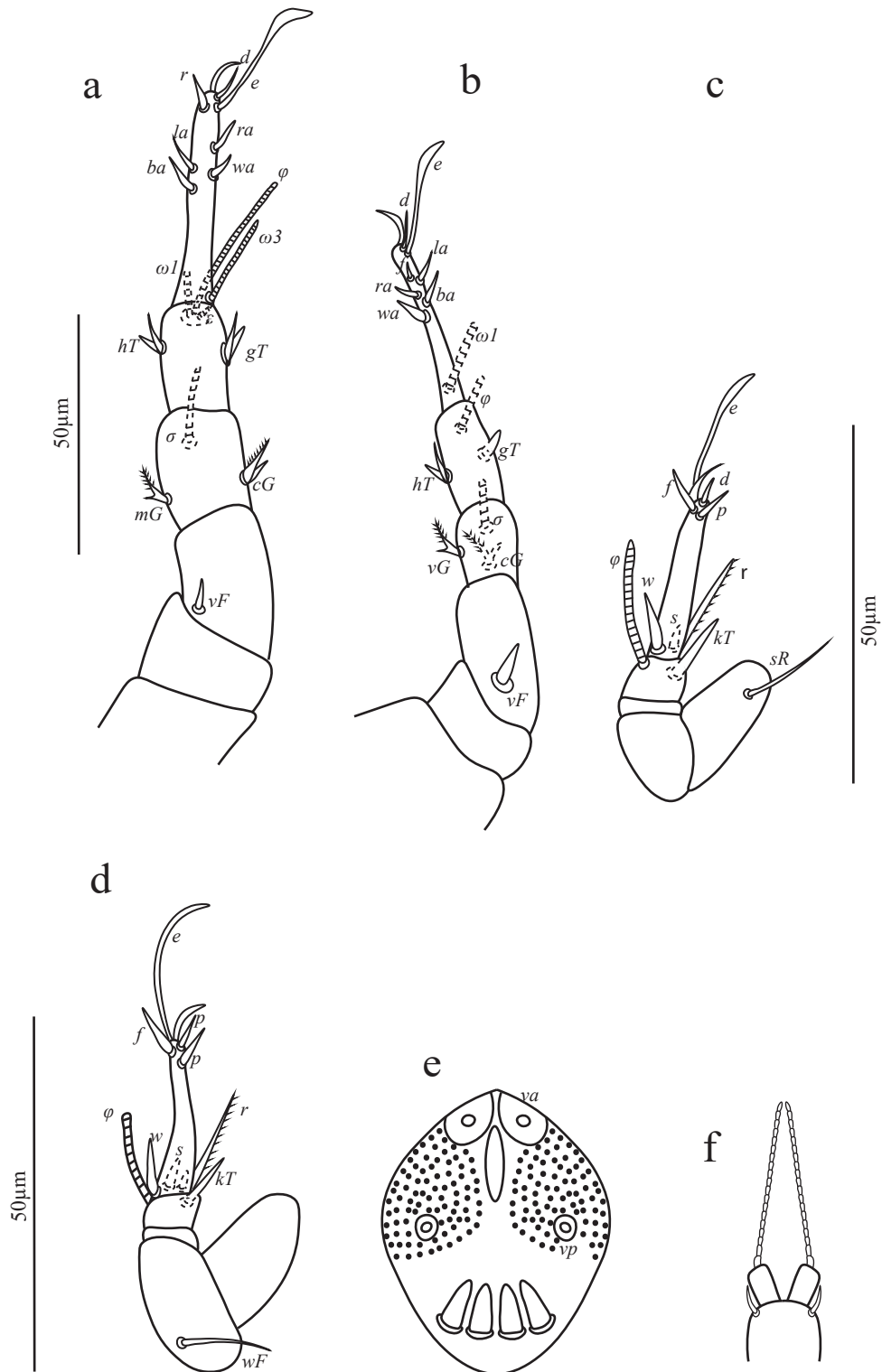


Fig. 1.126. *Curculanoetus keralensis* sp. nov. a.Leg I, b.Leg II, c.Leg III, d.Leg IV, e.anal plate, f. Gnathosoma.

Canestriniella batocera sp. nov.

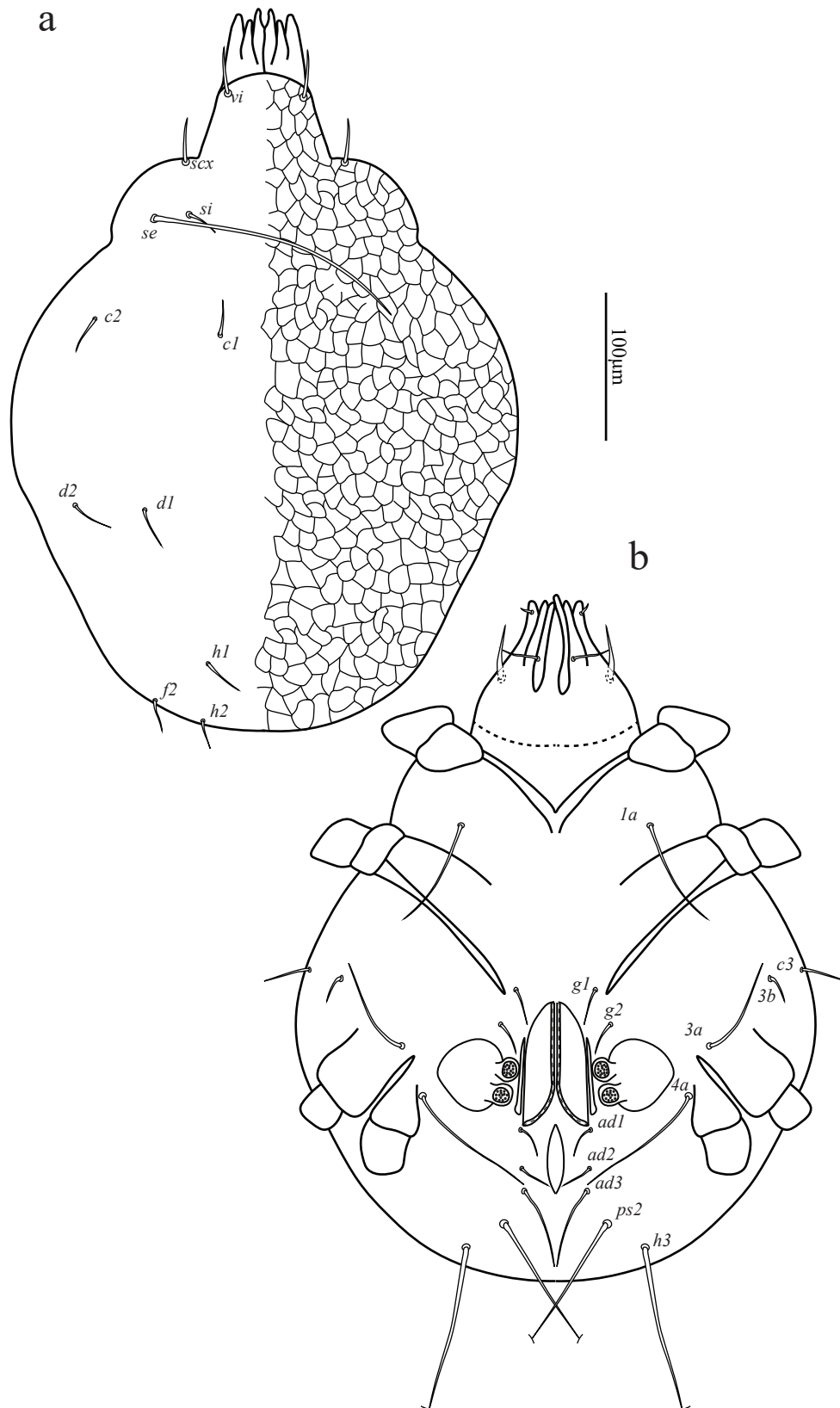


Fig. 1.128. *Canestriniella batocera* sp. nov. Adult female. a.Dorsum, b.Venter

Canestriniella batocera sp. nov.

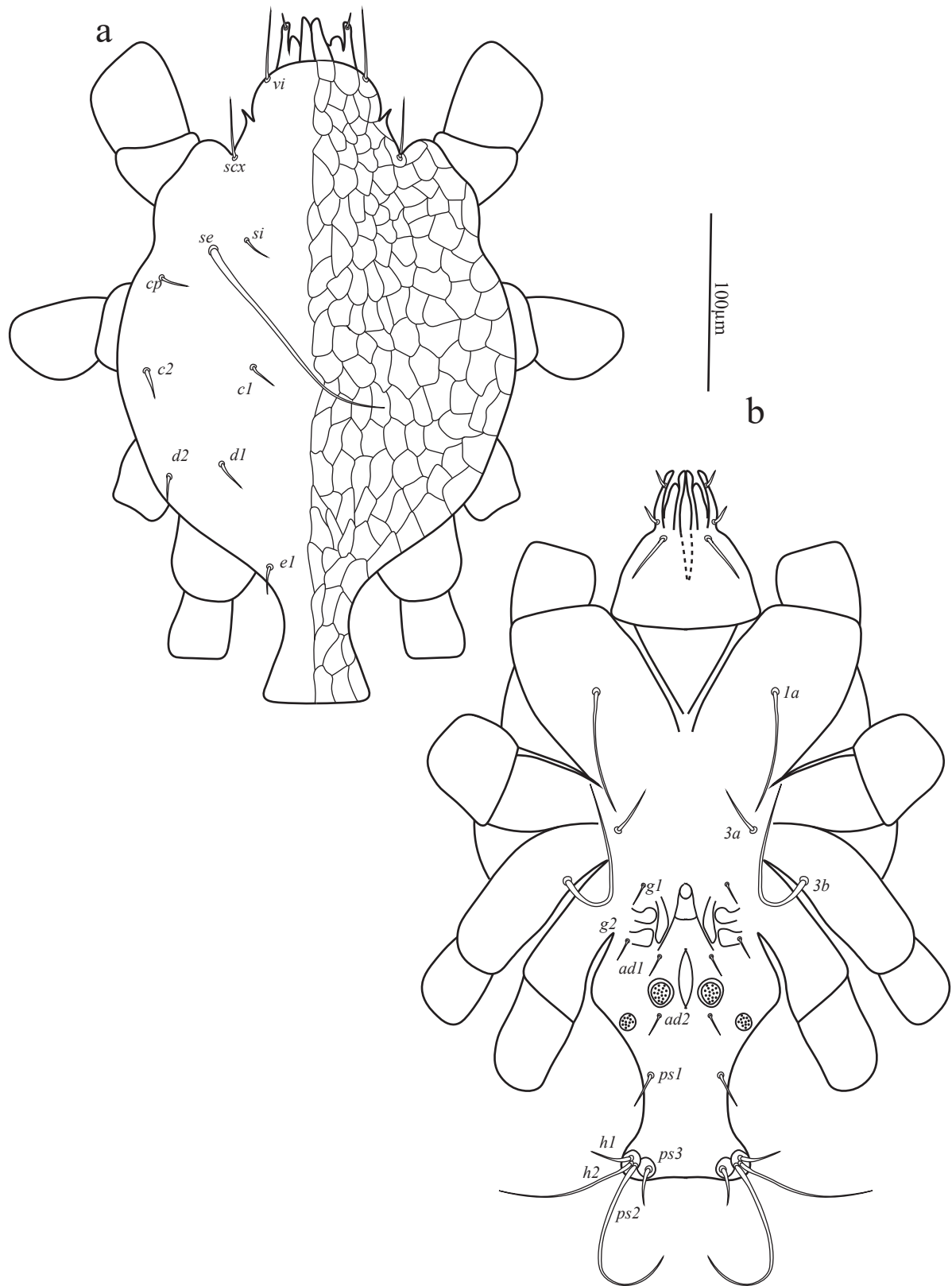


Fig.1.129. *Canestriniella batocera* sp. nov. Adult male. a.Dorsum, b.Venter

Canestriniella batocera sp. nov.

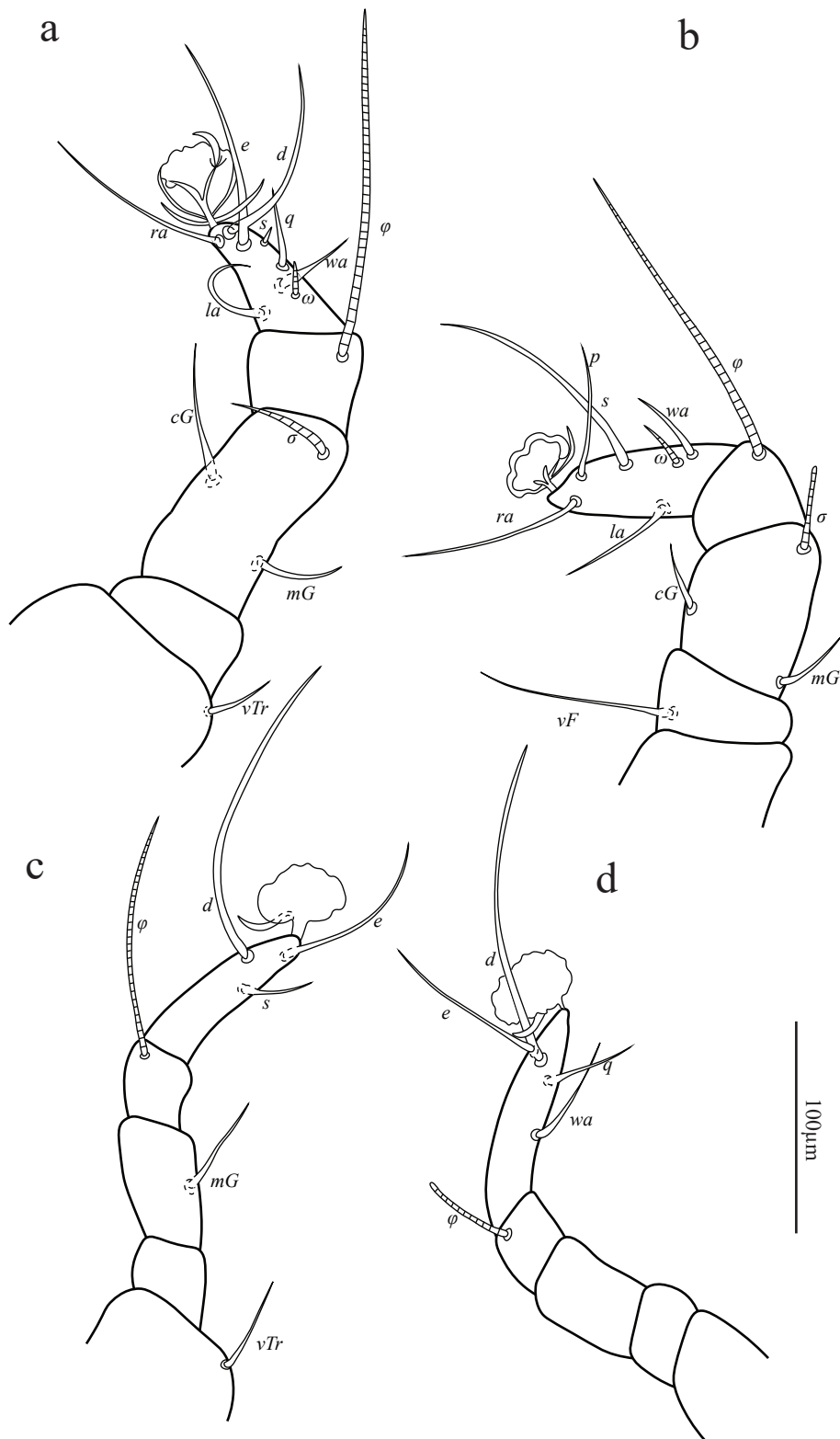


Fig. 1.130. *Canestriniella batocera* sp. nov. a. Leg I, b. Leg II, c. Leg III, d. Leg IV.

Athogavia oryctae sp. nov.

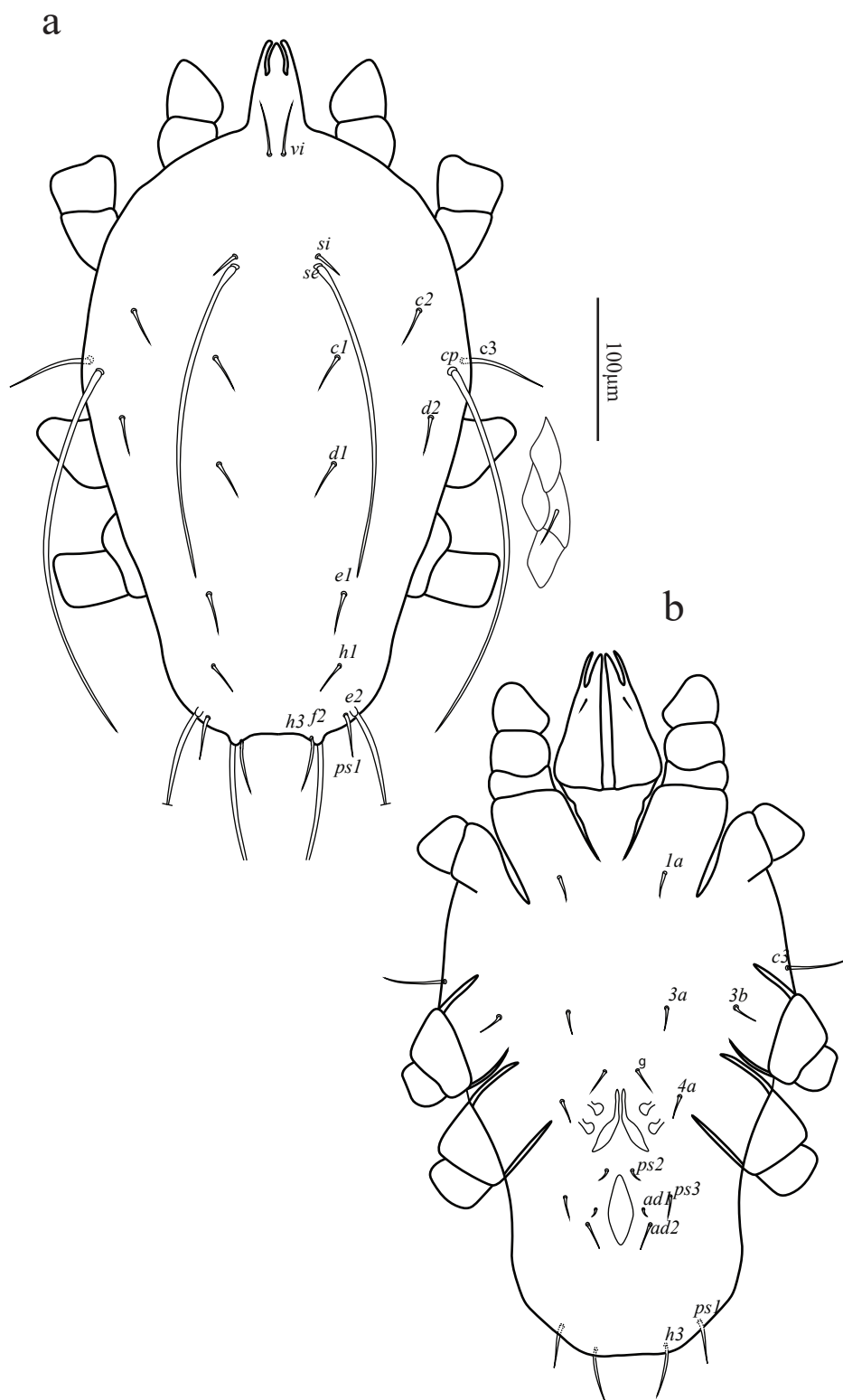


Fig. 1.132. *Athogavia oryctae* sp. nov. Adult female. a.Dorsum, b.Venter

Athogavia oryctae sp. nov.

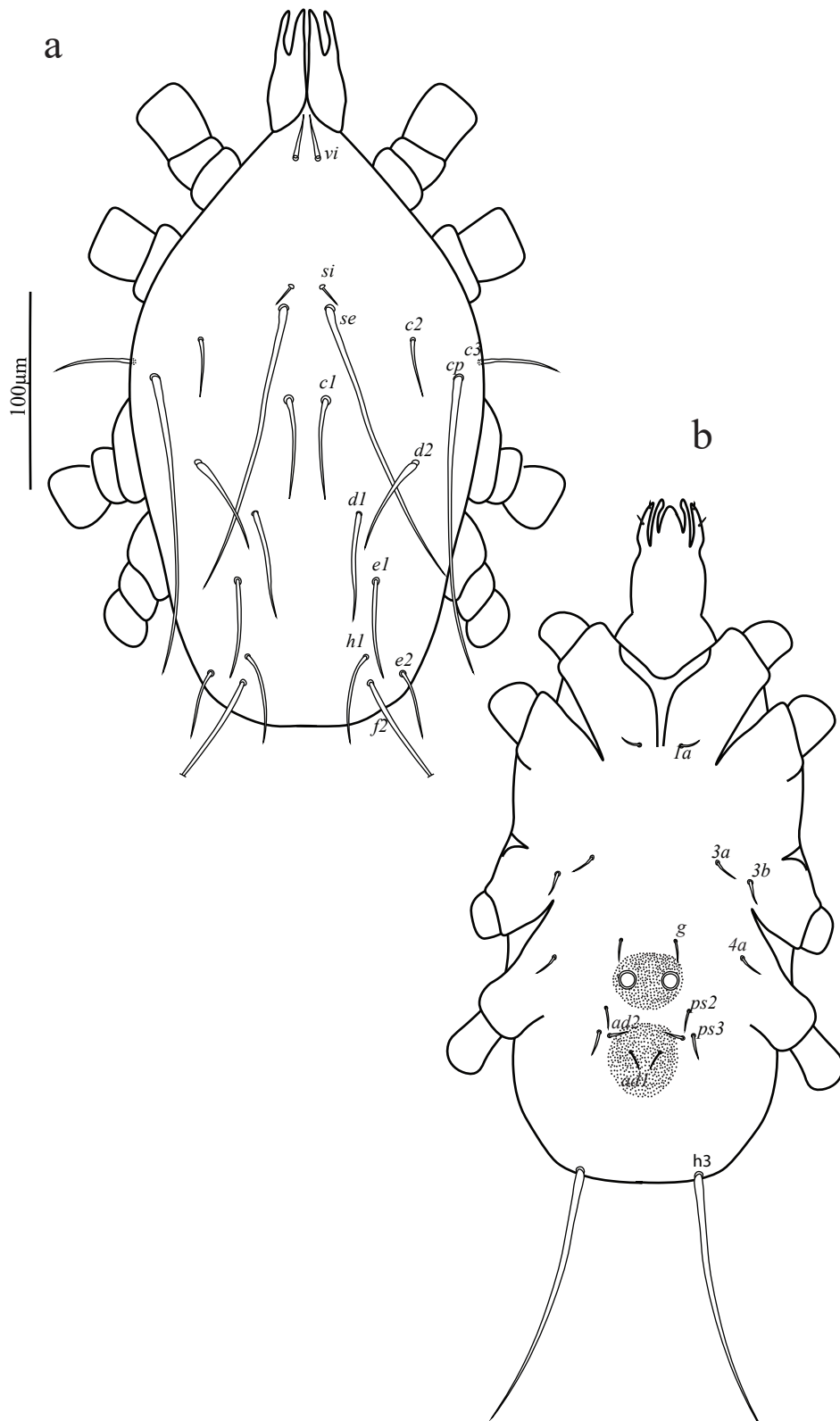


Fig. 1.133. *Athogavia oryctae* sp. nov. Adult male. a.Dorsum, b.Venter

Athogavia oryctae sp.nov.

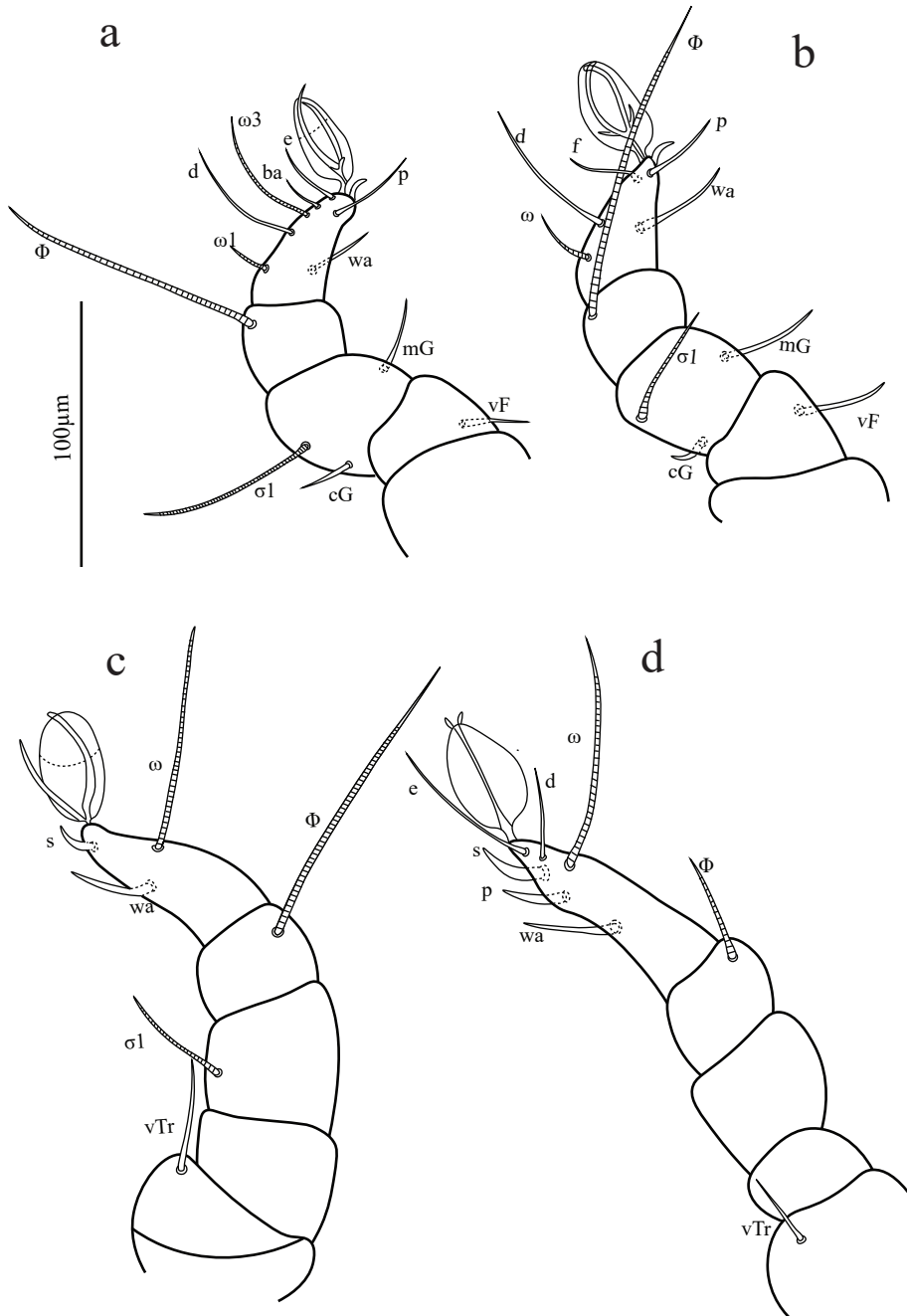


Fig. 1.134. *Athogavia oryctae* sp.nov. a.Leg I, b.Leg II, c.Leg III, d.Leg IV.

Congovidia glossinae Fain & Elsen, 1971

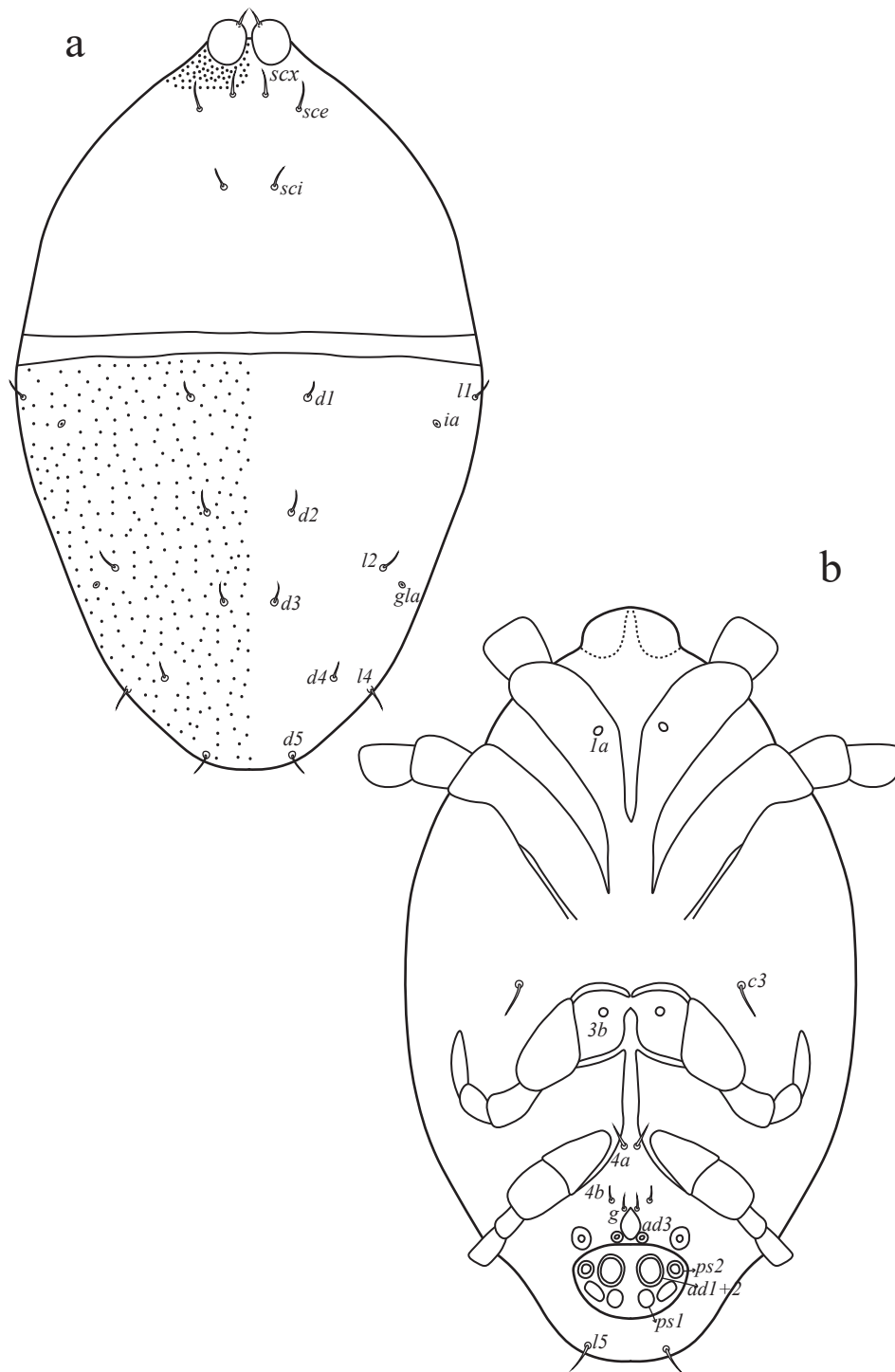


Fig. 1.136. *Congovidia glossinae* Deutonymph a.Dorsum, b.Venter

Congovidia glossinae Fain & Elsen, 1971

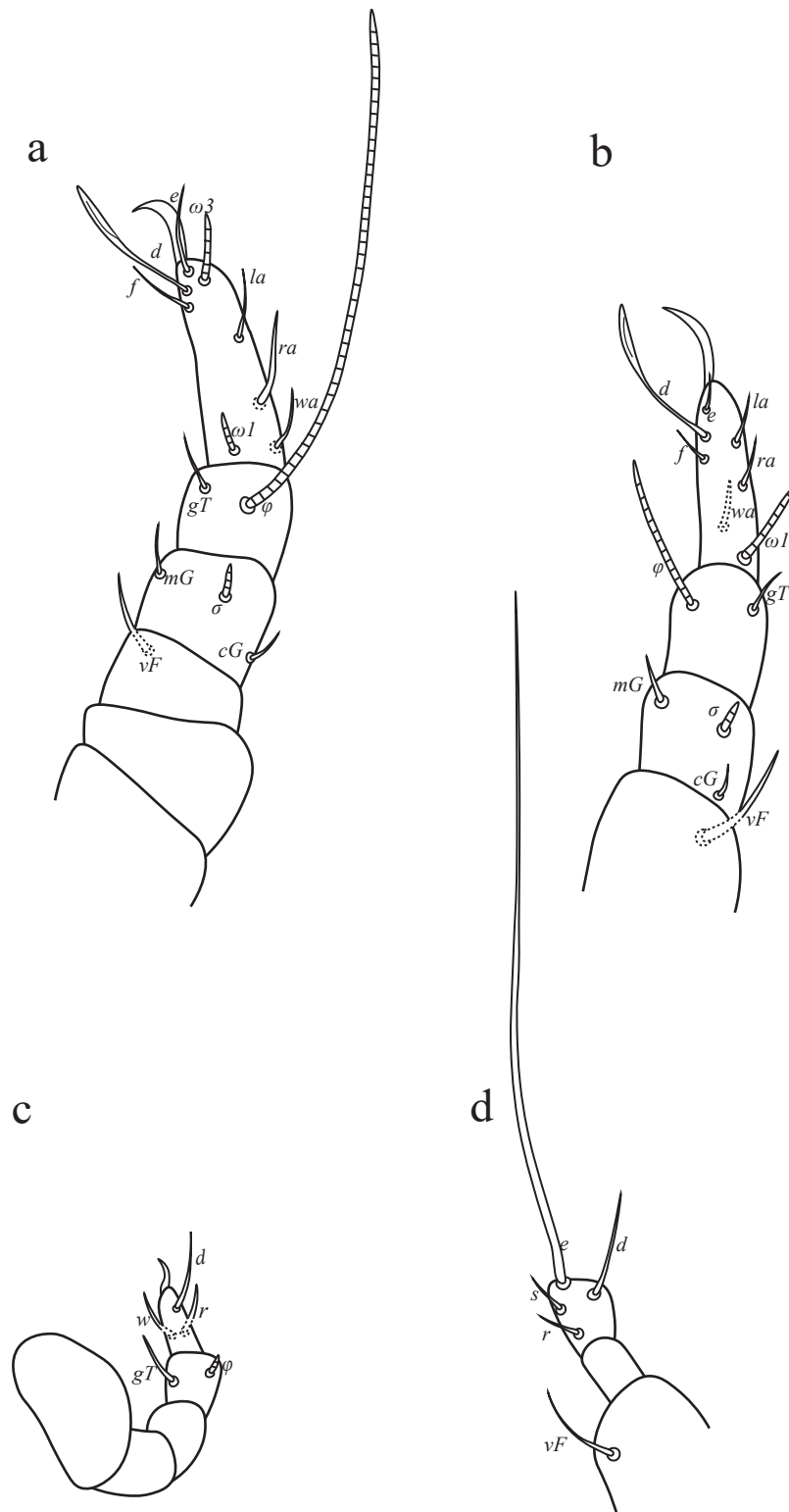


Fig. 1.137. *Congovidia glossinae* Deutonymph. a.Leg I, b.Leg II, c.Leg III, d.Leg IV.

Procalvolia sp.

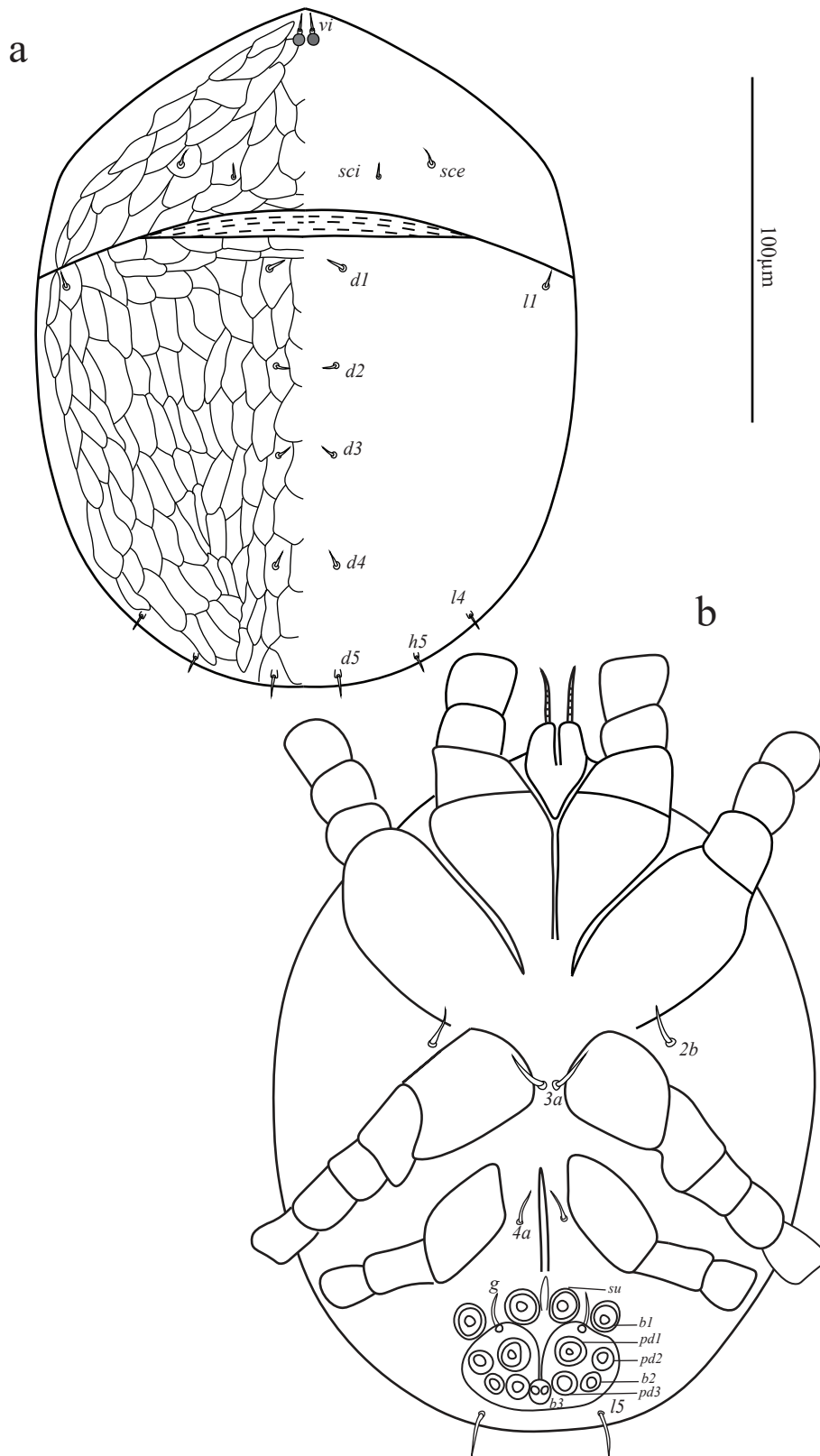


Fig. 1.138. *Procalvolia* sp. Deutonymph a.Dorsum, b.Venter

Procalvolia sp.

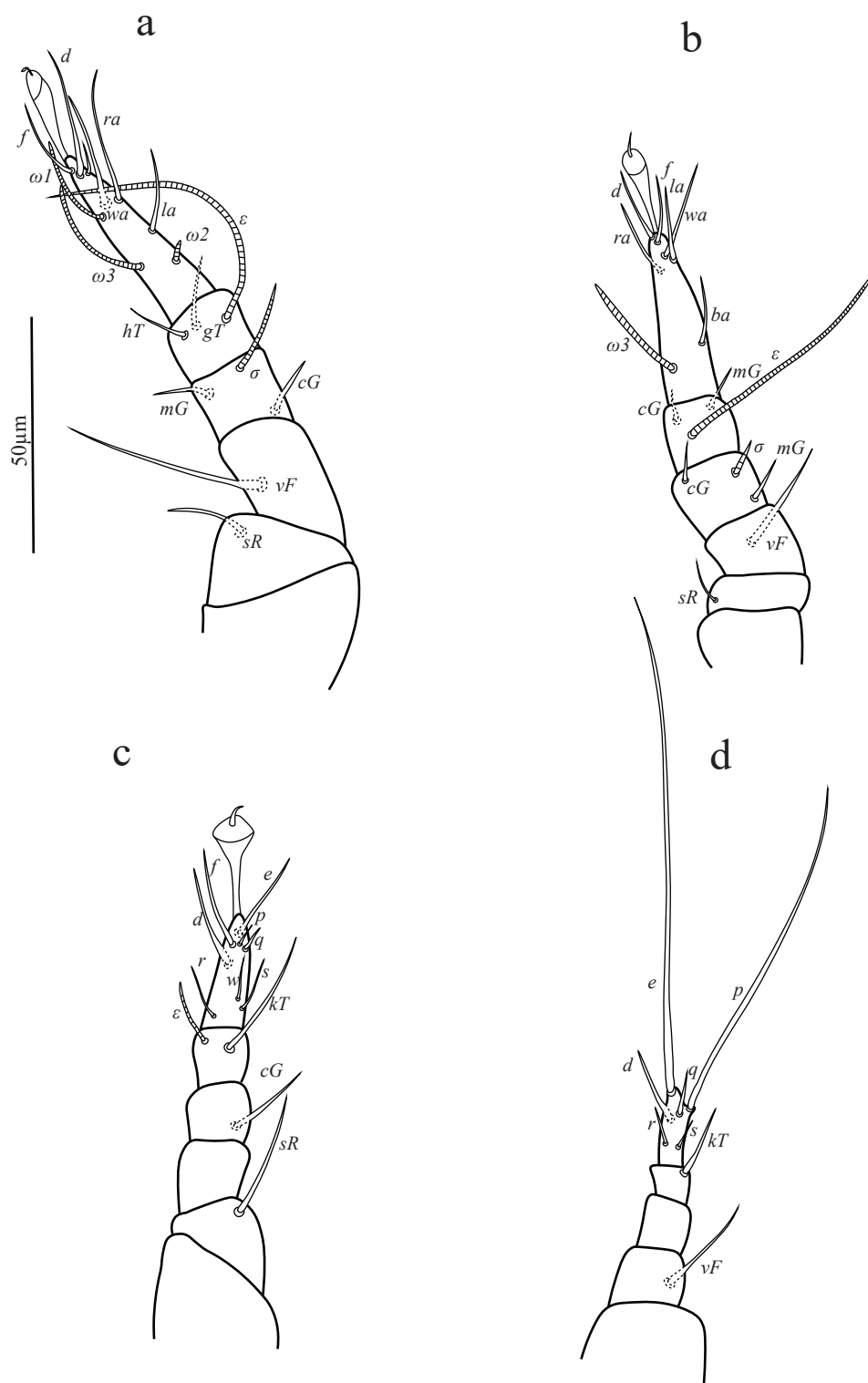


Fig. 1.139. *Procalvolia* sp. Deutonymph a.Leg I, b.Leg II, c.Leg III, d.Leg IV.

Acarus solimani Eraky, 1999

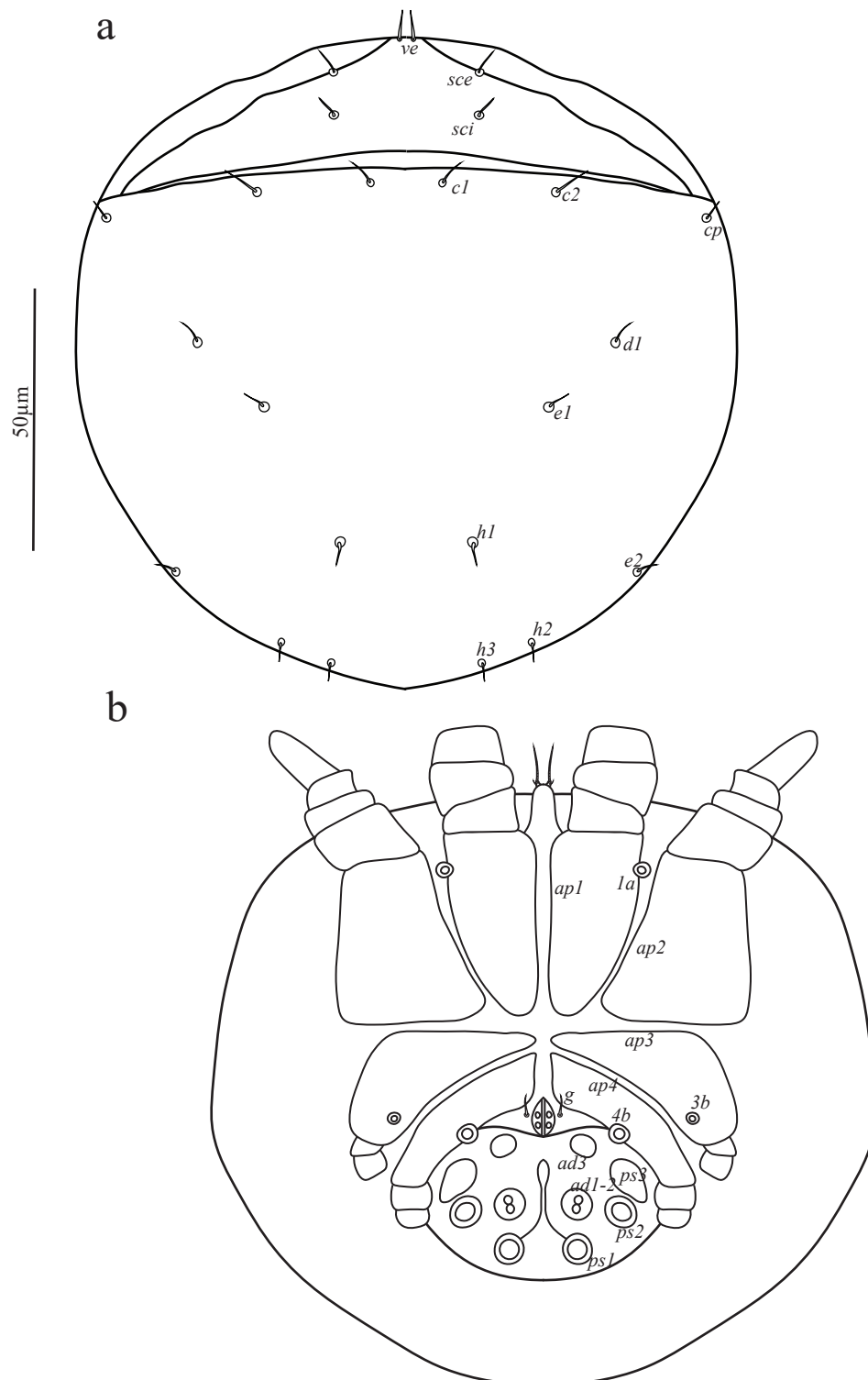


Fig. 1.140. *Acarus solimani* Deutonymph a. Dorsum, b. Venter

Acarus solimani Eraky, 1999

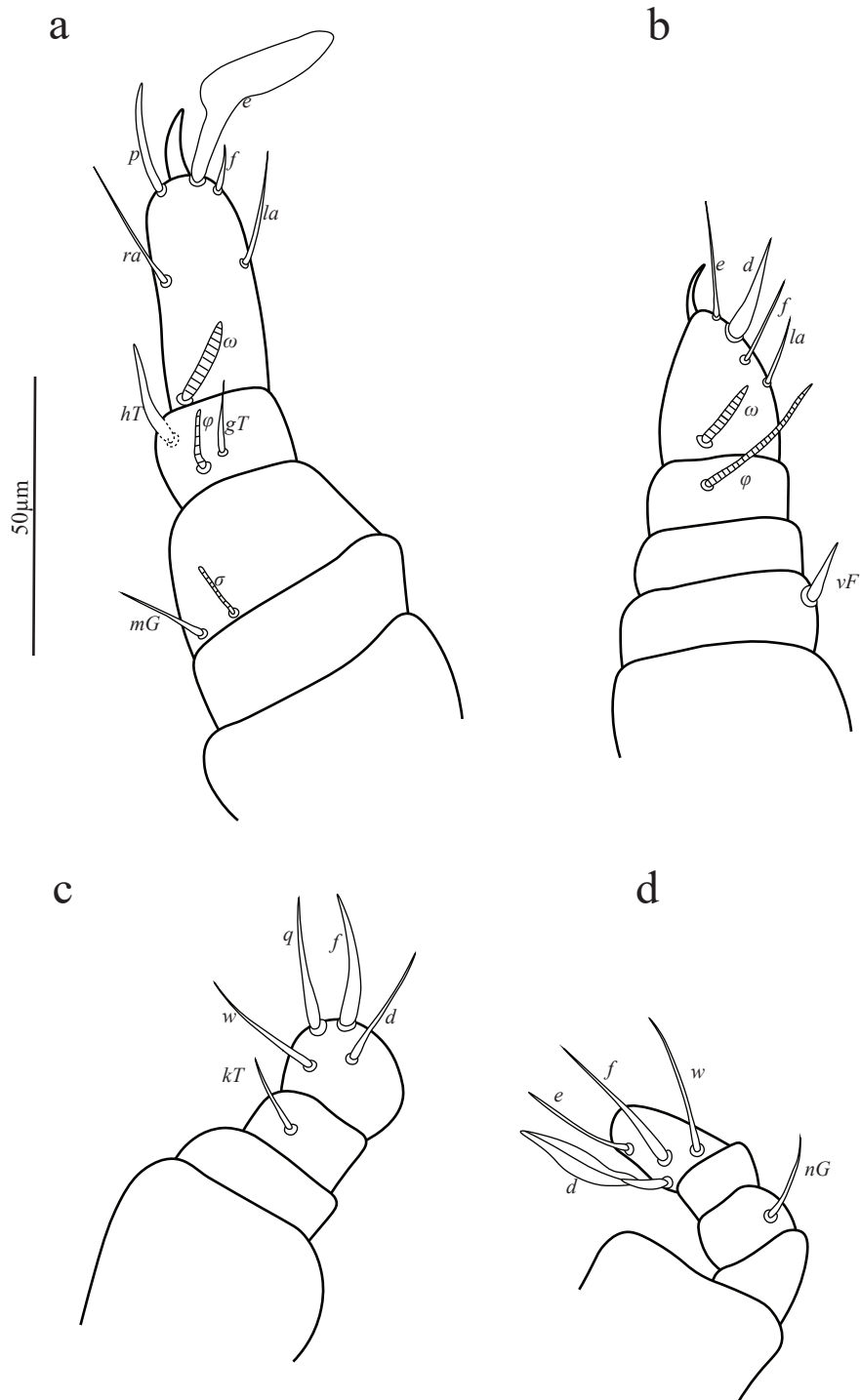


Fig. 1.141. *Acarus solimani* Deutonymph a.Leg I, b.Leg II, c.Leg III, d.Leg IV

Rhizoglyphus vicantus Manson, 1977

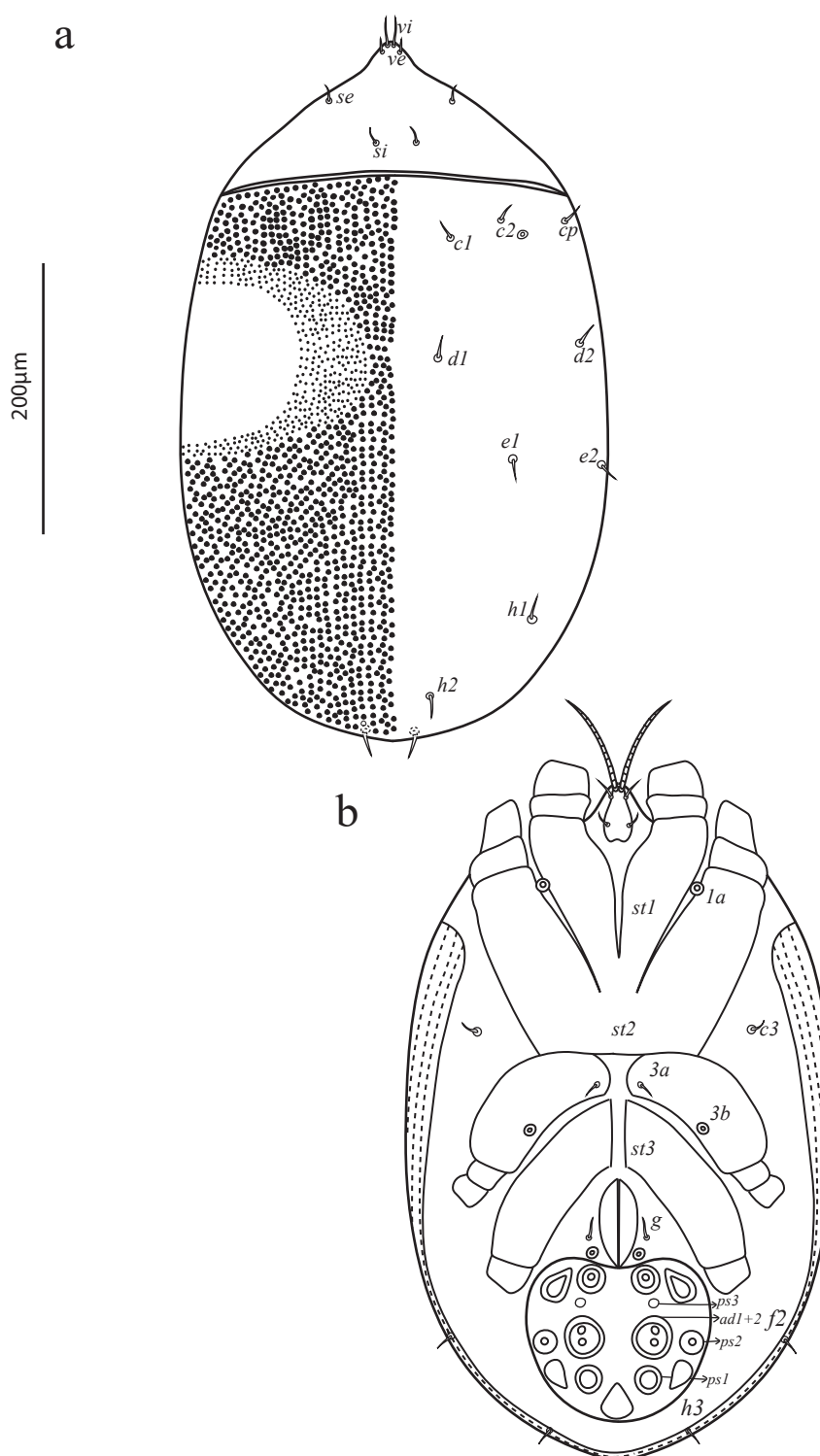


Fig. 1.142. *Rhizoglyphus vicantus* Deutonymph a. Dorsum, b. Venter

Rhizoglyphus vicantus Manson, 1977

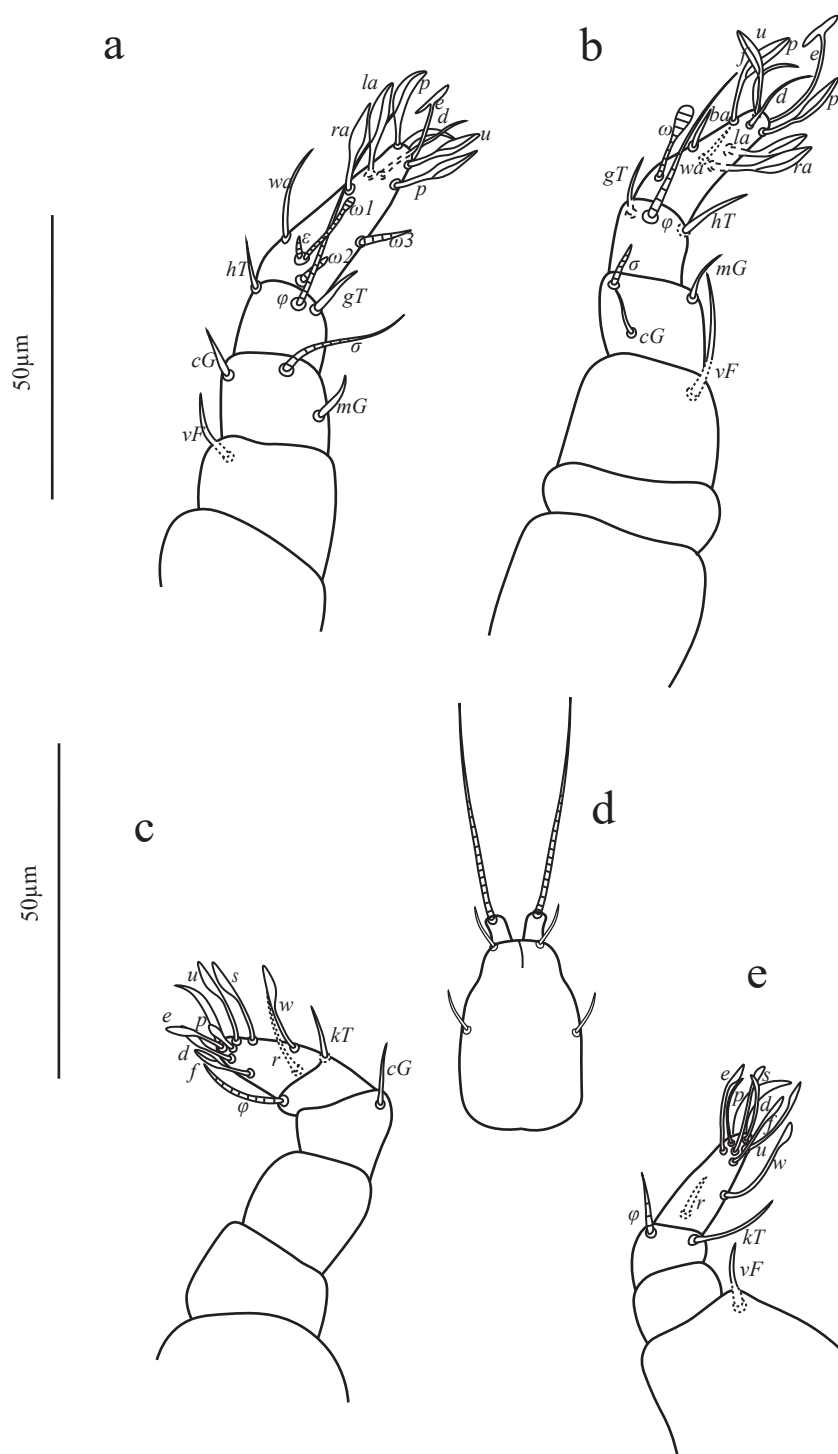


Fig. 1.143. *Rhizoglyphus vicantus* Deutonymph a. Leg I, b. Leg II, c. Leg III, d. Gnathosoma, e. Leg IV

Acotyledon tariqi Ashfaq, Sher, Chaudhri and Aslam, 1987

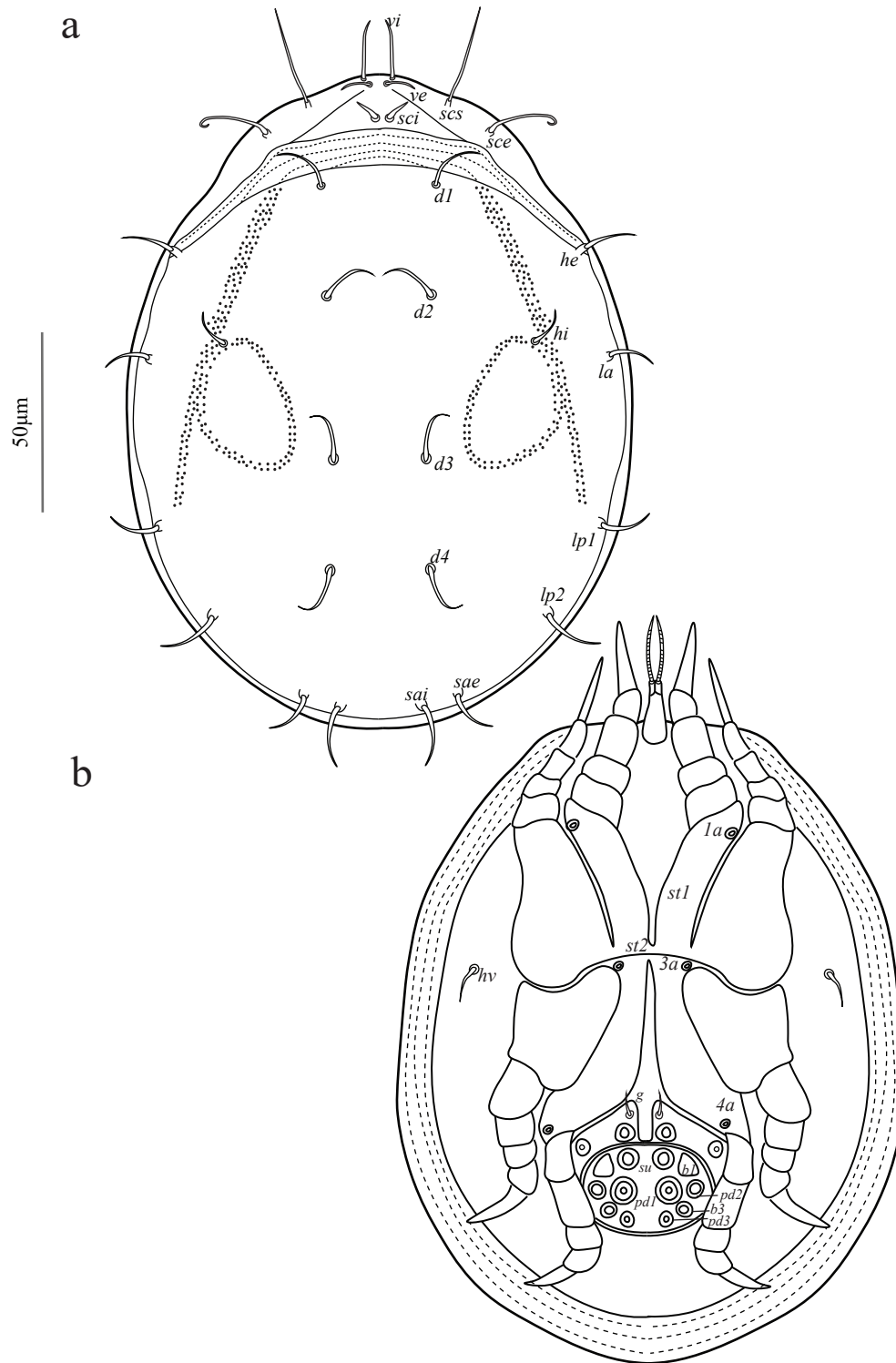


Fig. 1.144. *Acotyledon tariqi* Deutonymph a.Dorsum, b.Venter

Acotyledon tariqi Ashfaq, Sher, Chaudhri and Aslam, 1987

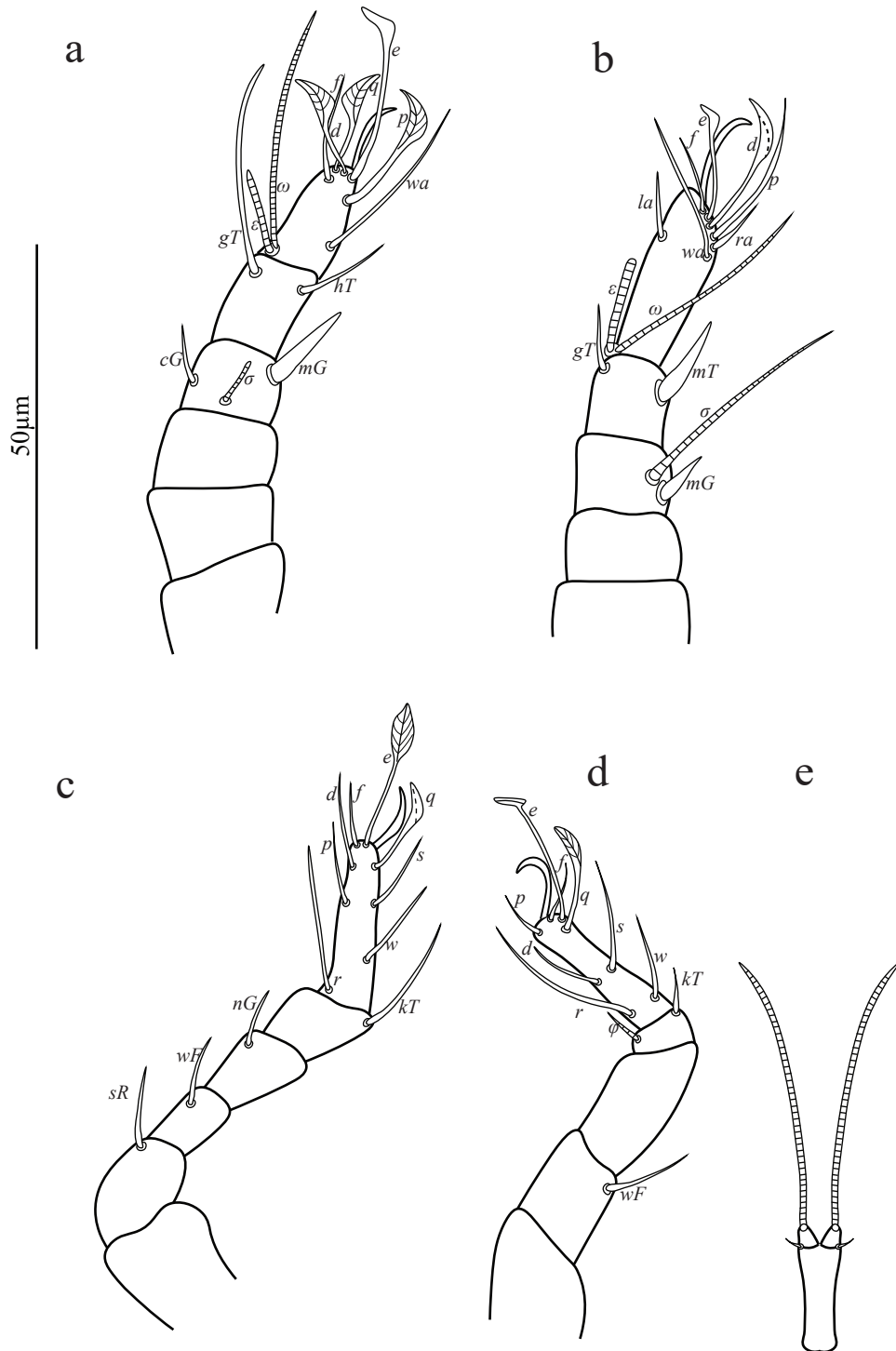


Fig. 1.145. *Acotyledon tariqi*. a. Leg I, b. Leg II, c. Leg III, d. Leg IV, e. Gnathosoma

Sancassania boharti Cross, 1968

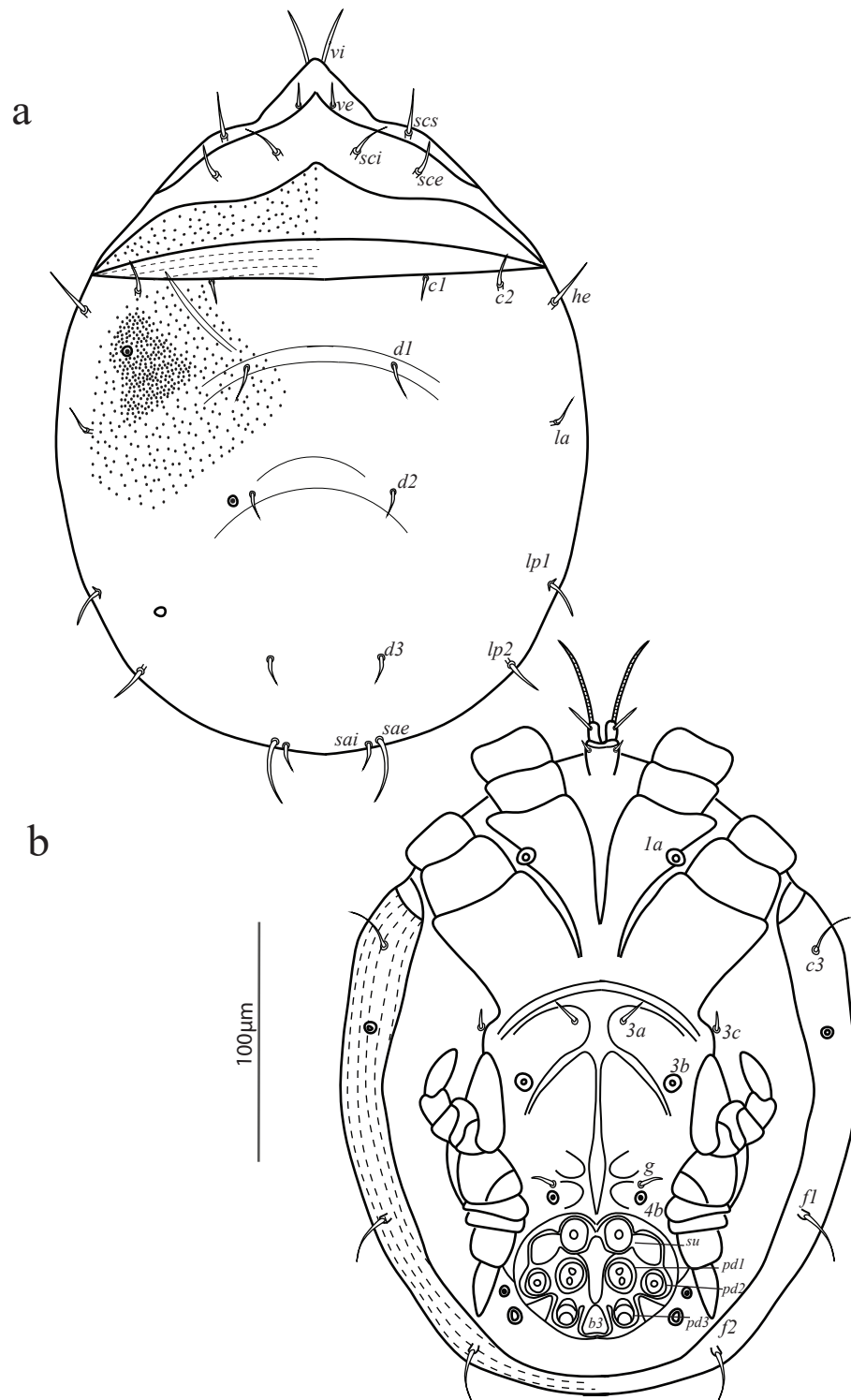


Fig. 1.146. *Sancassania boharti* Deutonymph a. Dorsum, b. Venter

Sancassania boharti Cross, 1968

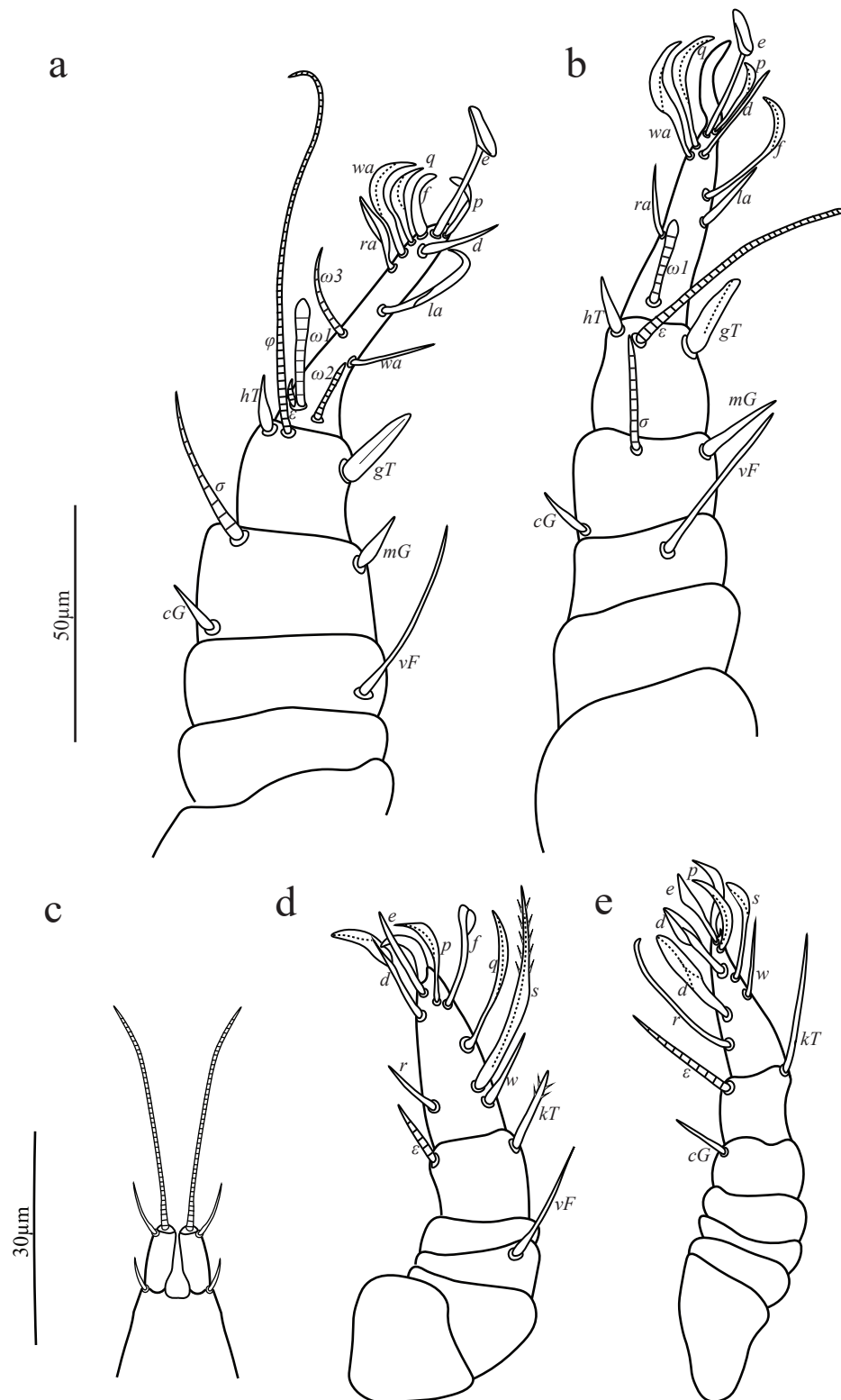


Fig. 1.147. *Sancassania boharti* Deutonymph a.Leg I, b.Leg II, c.Gnathosoma, d.Leg III, e.Leg IV

Schweibea sp.

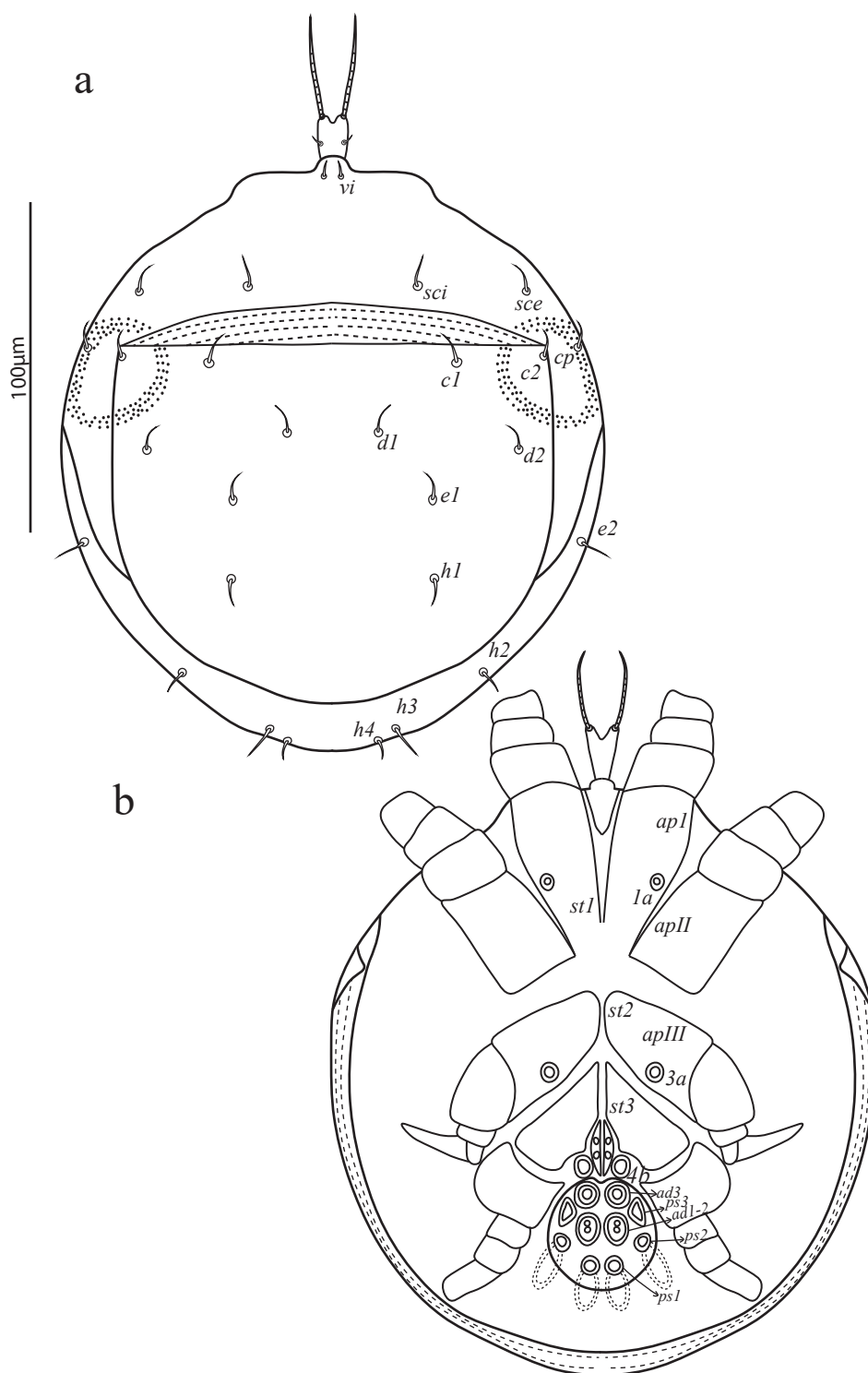


Fig. 1.148. *Schweibea* sp. Deutonymph a.Dorsum, b.Venter

Schweibea sp.

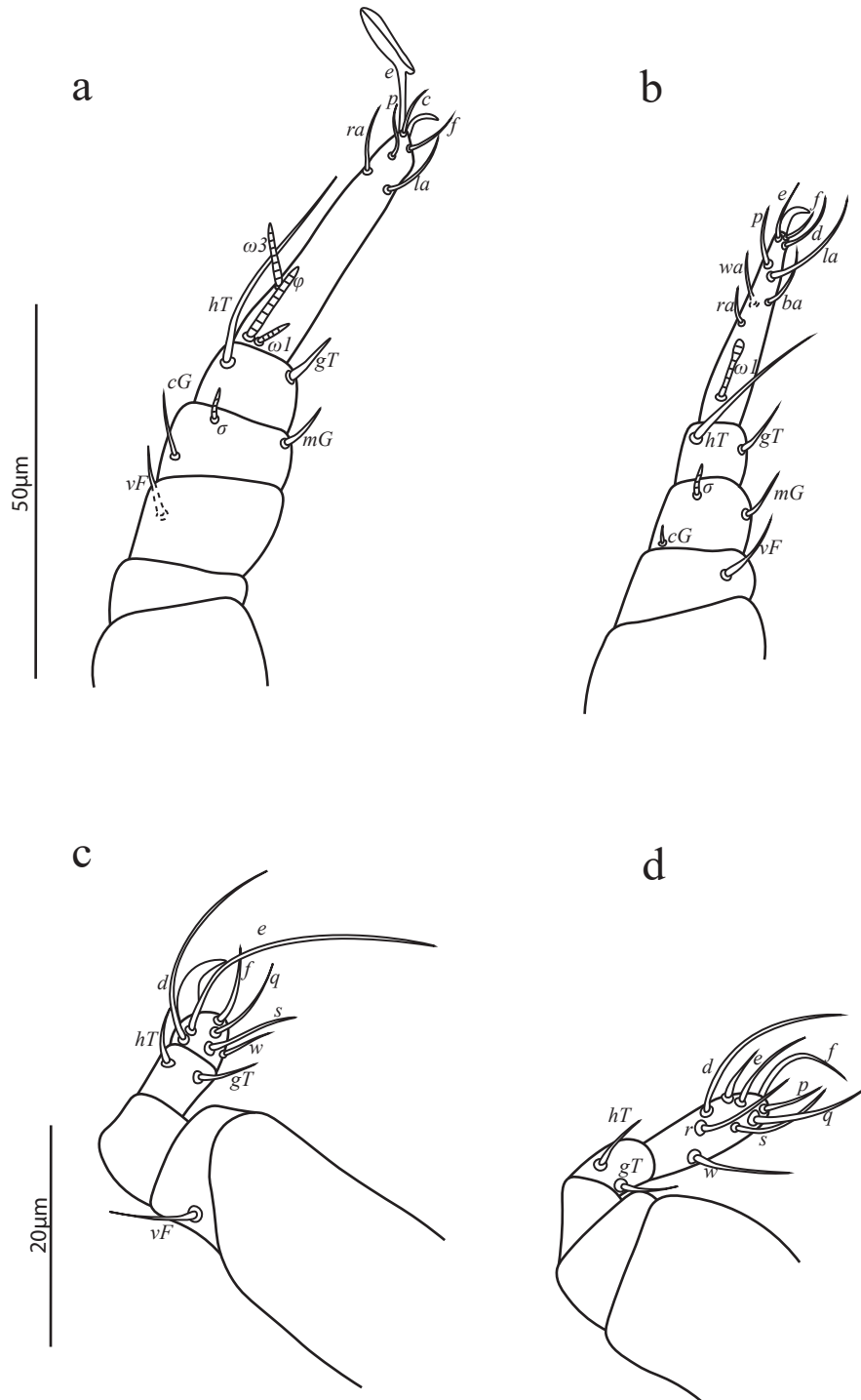


Fig. 1.149. *Schweibea* sp. Deutonymph a.Leg I, b.Leg II, c.Leg III, d.Leg IV.

Caloglyphus manuri Eraky and Osman, 2008

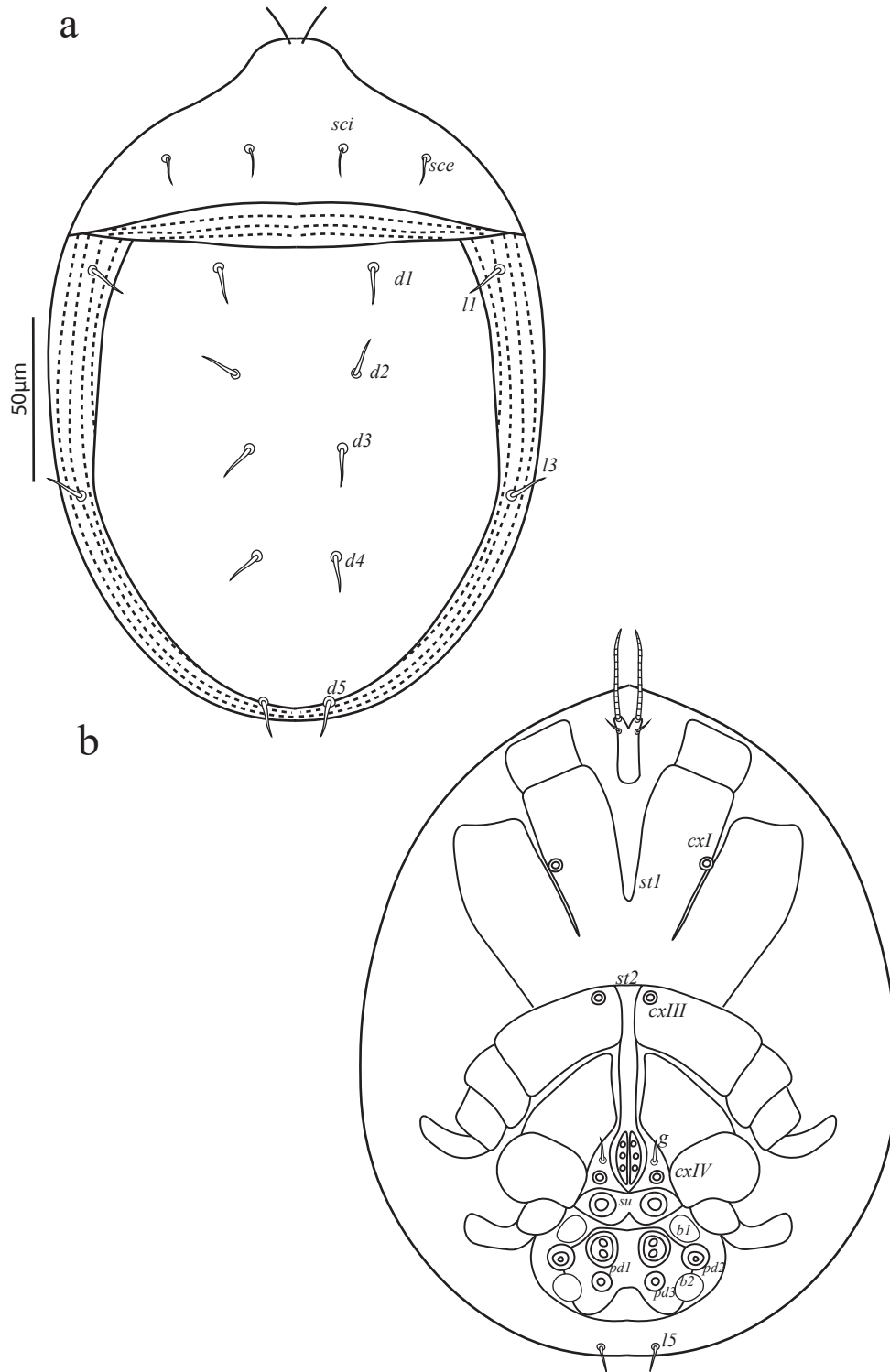


Fig. 1.150. *Caloglyphus manuri* Deutonymph a.Dorsum, b.Venter

Caloglyphus manuri Eraky and Osman, 2008

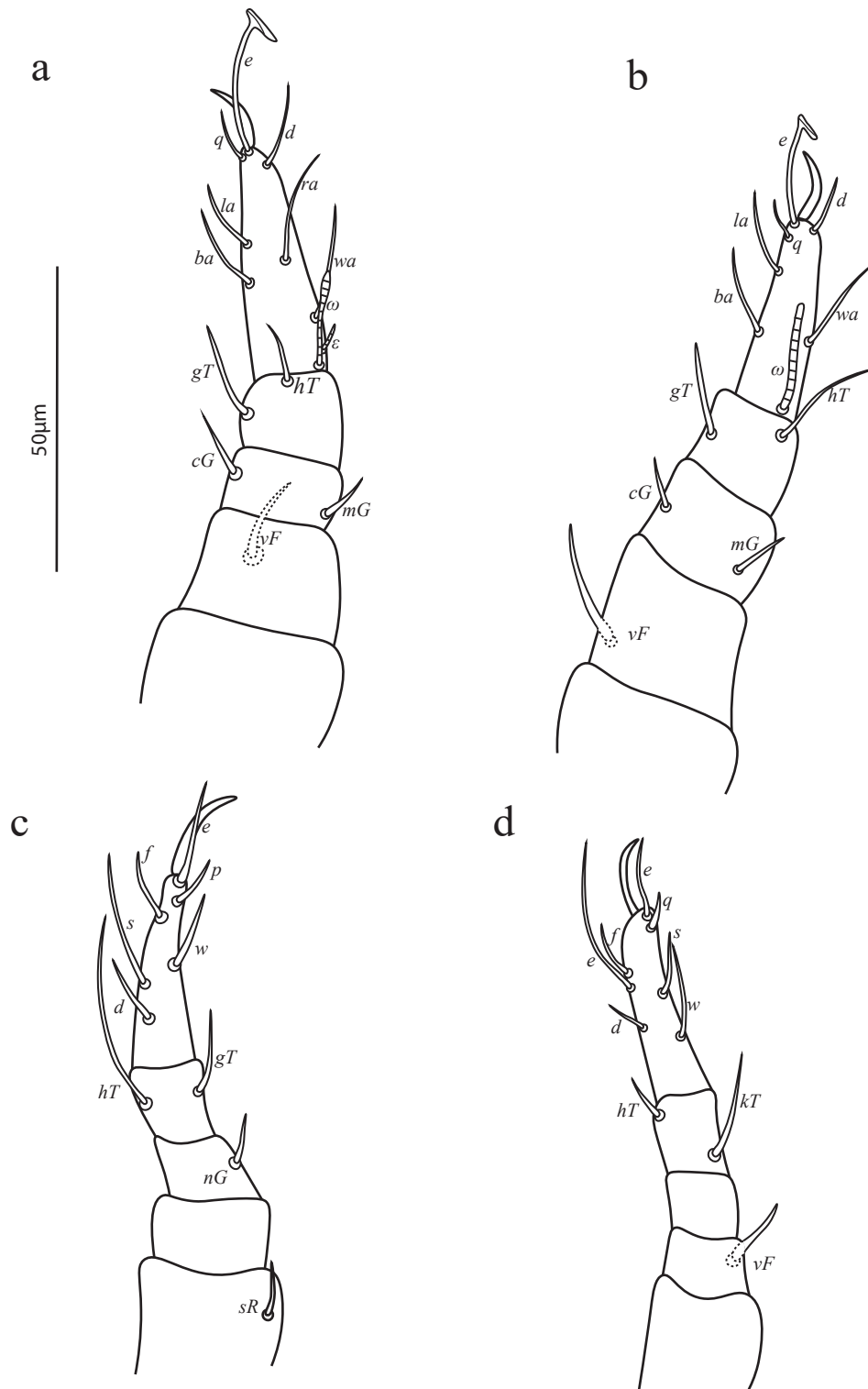


Fig. 1.151. *Caloglyphus manuri* Deutonymph a. Leg I, b. Leg II, c. Leg III, d. Leg IV

Caloglyphus subterraneousi Fakeer et al. 2014

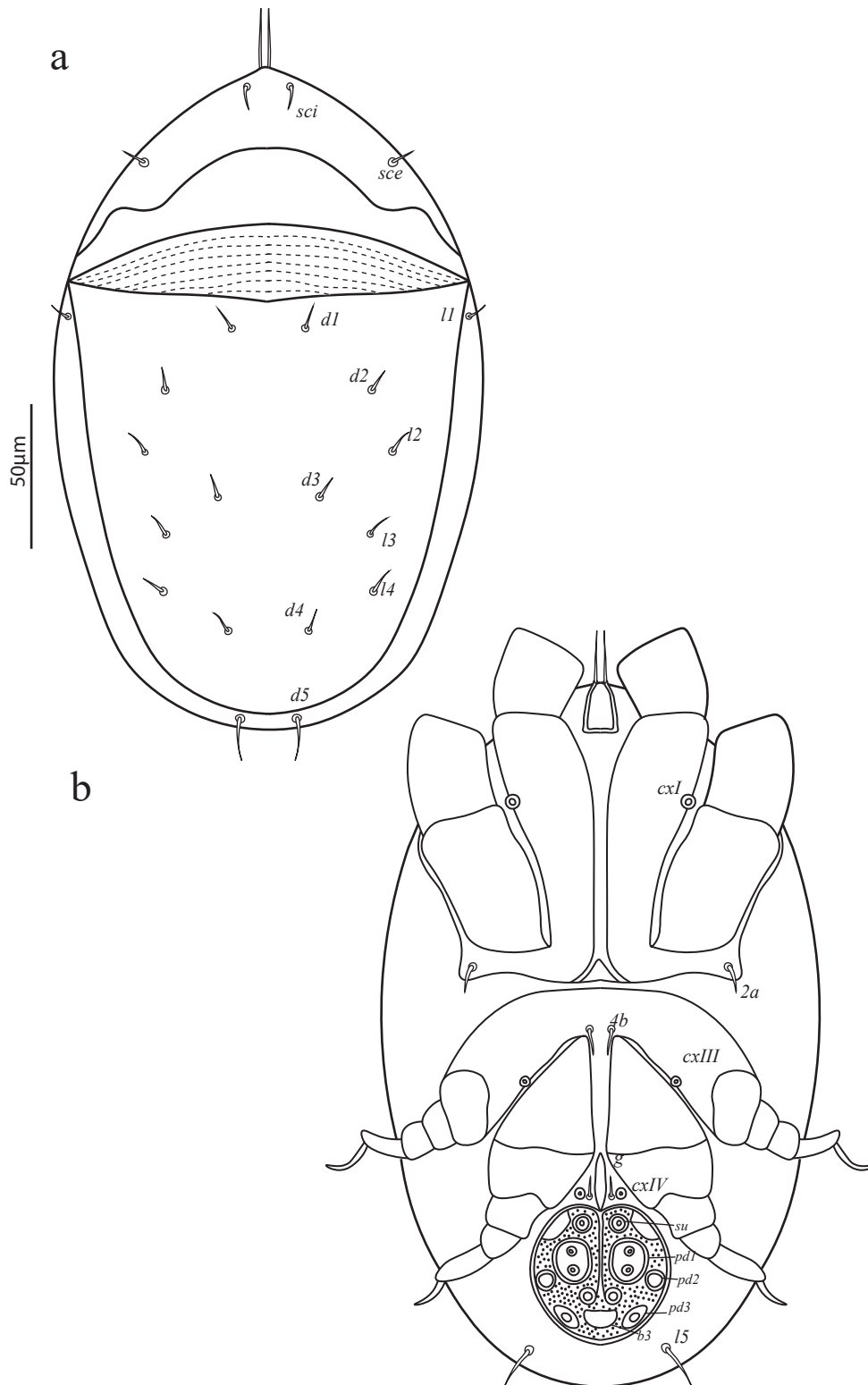


Fig. 1.152. *Caloglyphus subterraneousi* Deutonymph a.Dorsum, b.Venter

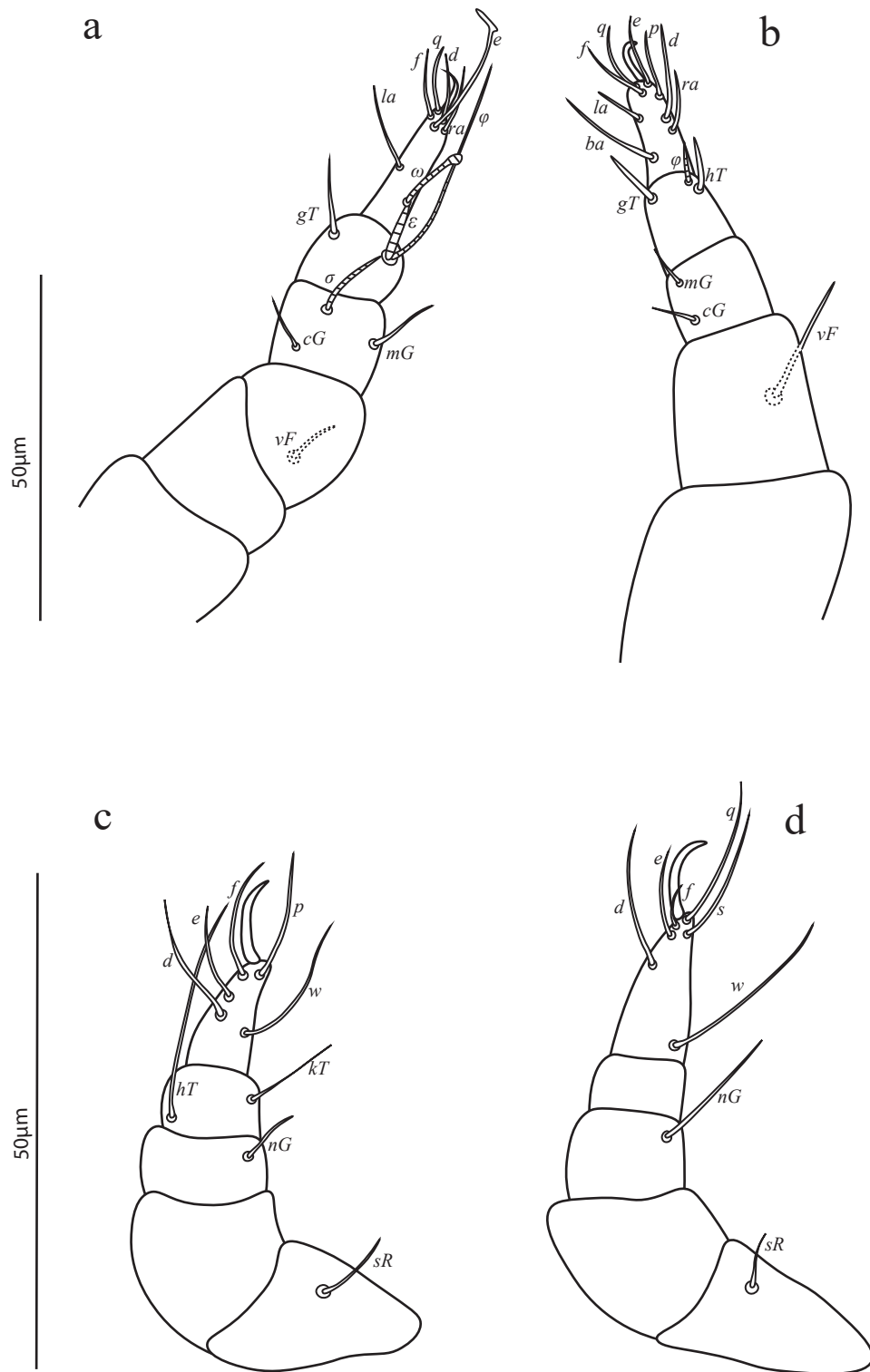


Fig. 1.153. *Caloglyphus subterraneousi* Deutonymph a.Leg I, b.Leg II, c.Leg III, d.Leg IV

Tyrophagus putrescentiae Schrank, 1781

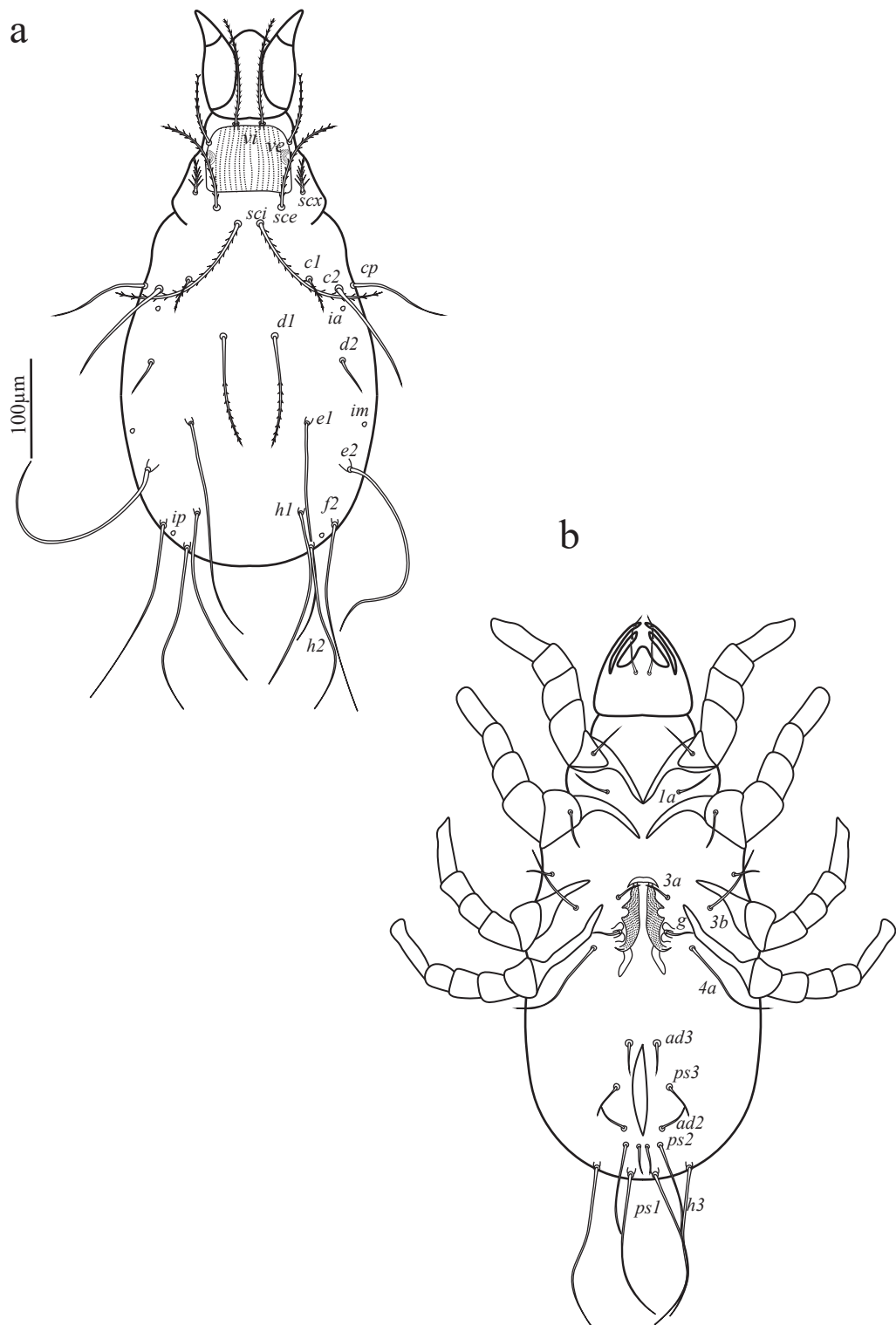


Fig. 1.154. *Tyrophagus putrescentiae* Adult Female a.Dorsum, b.Venter

Tyrophagus putrescentiae Schrank, 1781

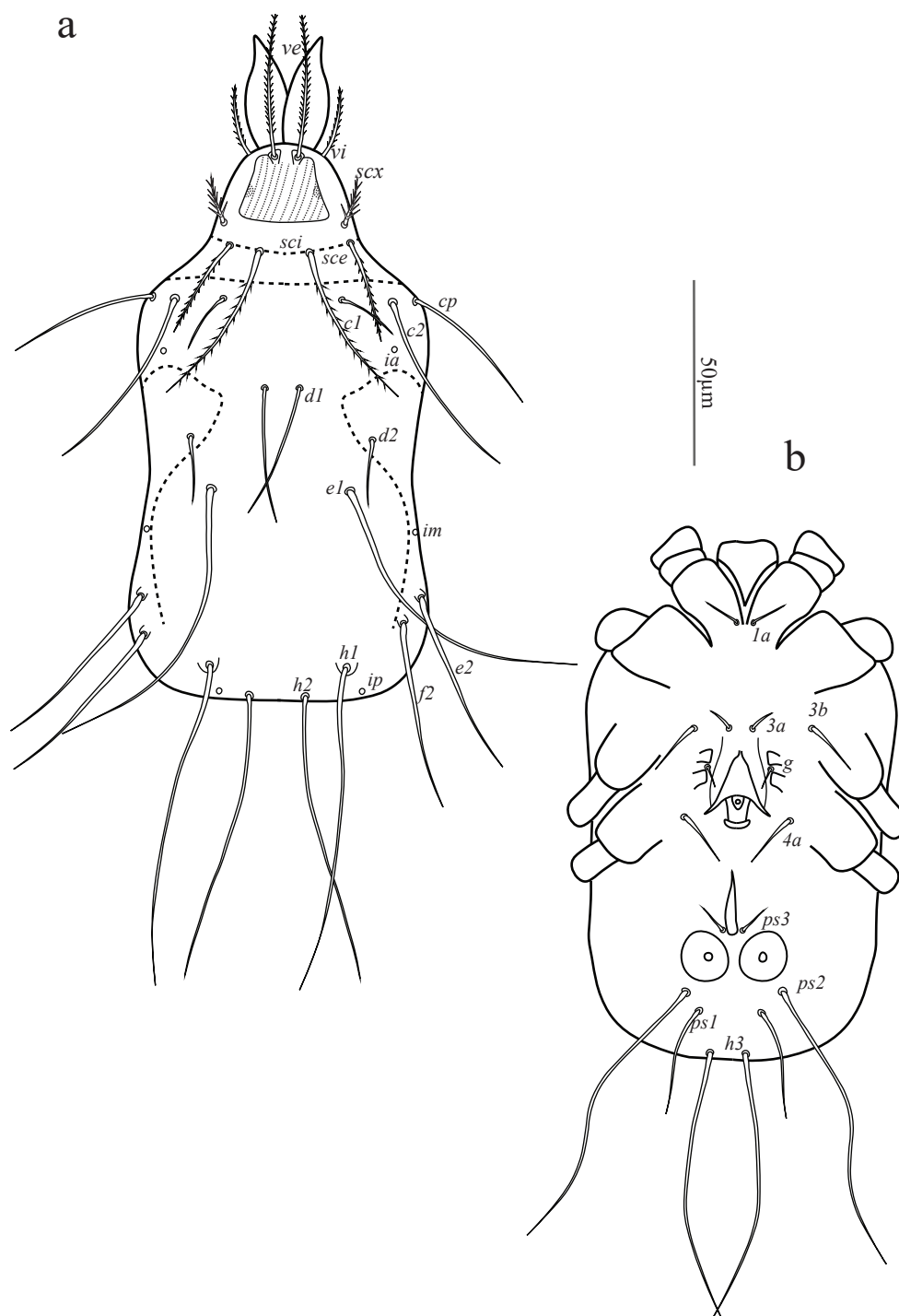


Fig. 1.155. *Tyrophagus putrescentiae* Adult male. a.Dorsum, b.Venter.

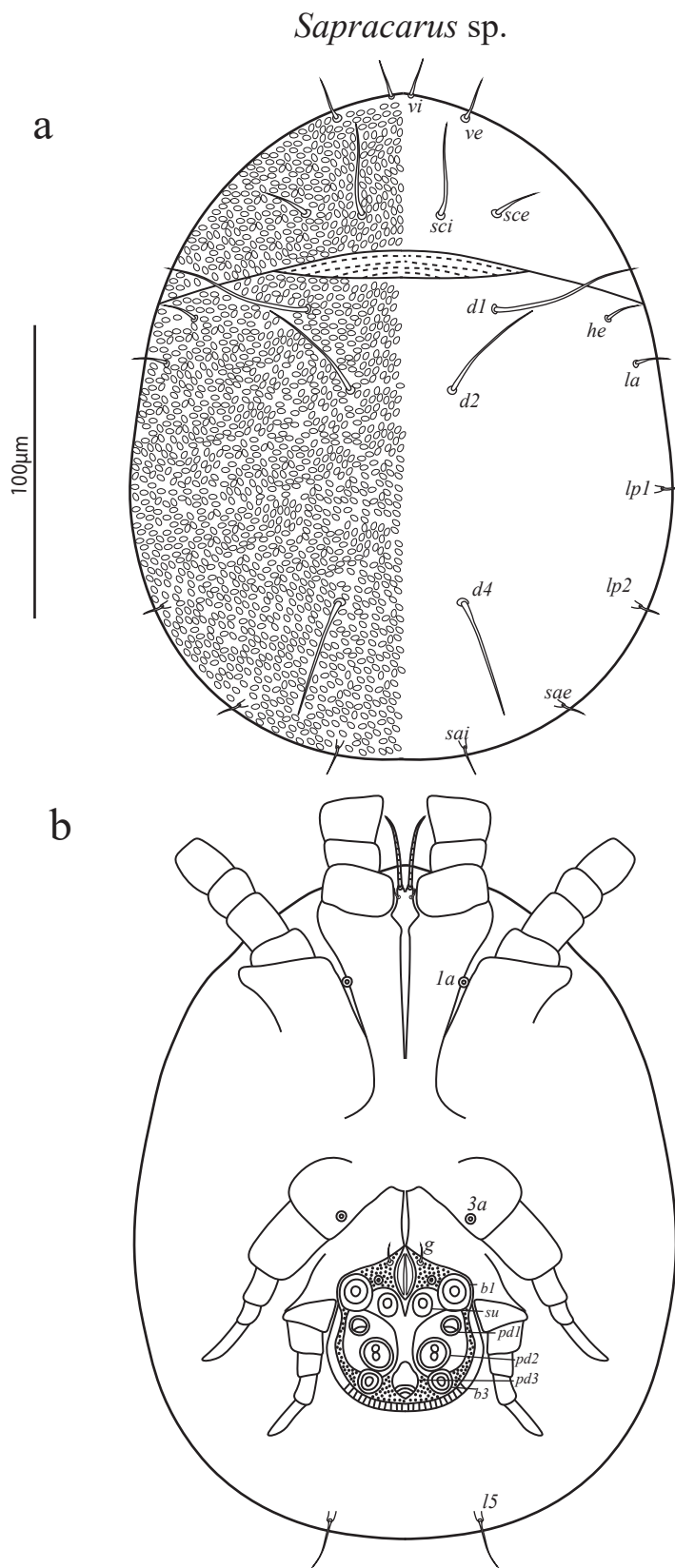


Fig. 1.156. *Sapracarus* sp. Deutonymph a. Dorsum, b. Venter

Sapracarus sp.

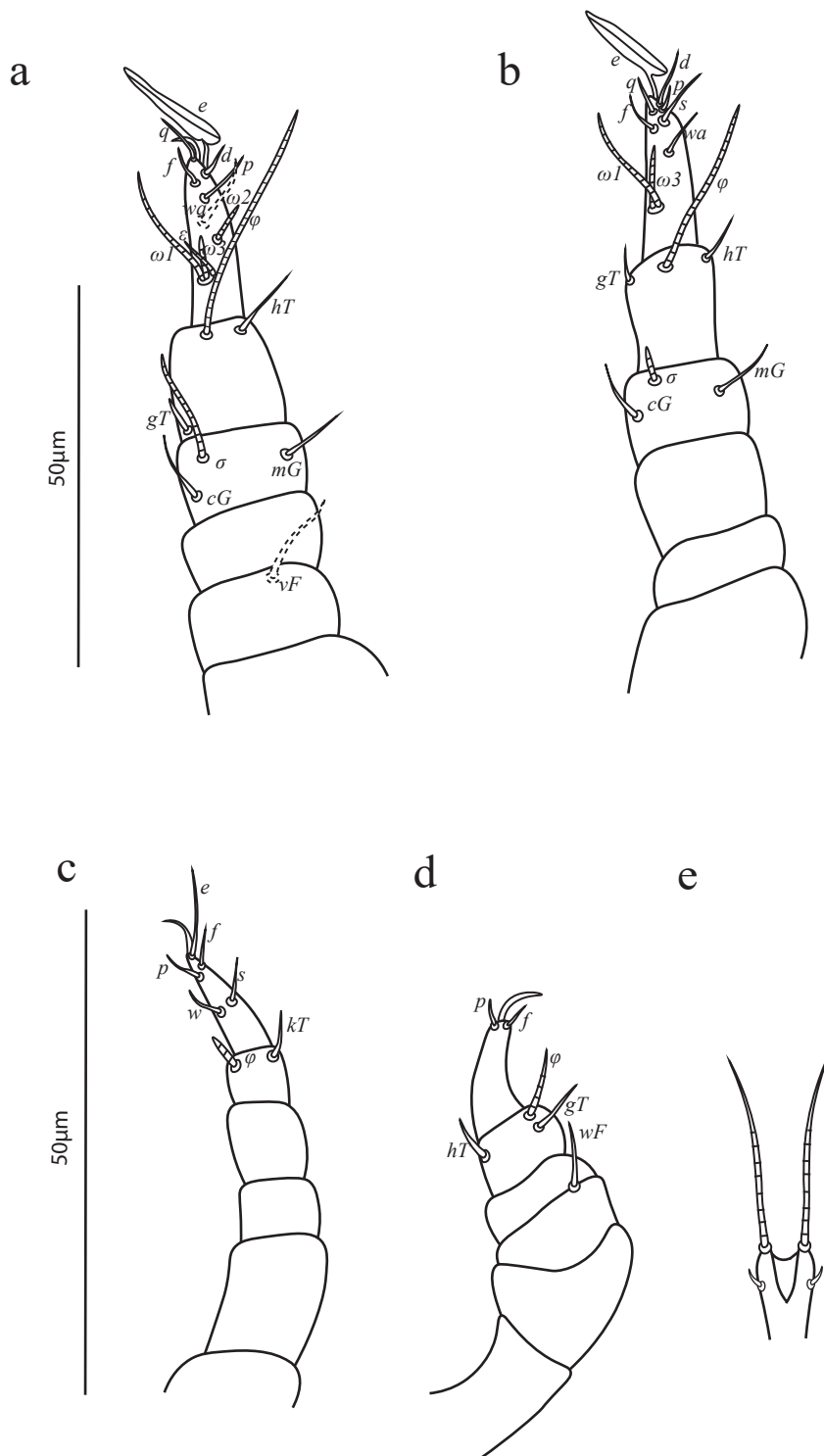


Fig. 1.157. *Sapracarus* sp. Deutonymph a.Leg I, b.Leg II, c.Leg III, d.Leg IV, e.Gnathosoma

Chapter 5

Discussion

A. Faunal diversity, relative abundance and distribution of mites recovered from the Insect hosts screened during the study

As the most successful group of animals on earth, insects exhibit wide distribution trend across the world and have become a part and parcel of mankind, both knowingly and unknowingly. Majority of insects are rated as beneficial to mankind owing to the incredible ecosystem services they perform in various areas of human interest such as biological control, biodegradation and nutrient cycling, soil formation, pollination and enhancement of agricultural production, aesthetic value, supplying products of commercial importance like honey, silk, lac etc. apart from their nutrient and medicinal values. Despite their multiple levels of beneficial significance, some of the insect species do serve various notorious roles as pests, thereby qualified themselves as a major threat to agricultural production, as well as their adverse impact on the health and wealth of mankind by inducing varied kinds of diseases, as parasites, vectors and pathogens. The extensive damage resulting from insect attack to crop production has become a major challenge to the food security of mankind, necessitating their eradication at any cost. The prolonged research along this line ended up in the discovery of varied kinds of insecticides, majority of which were proved to be harmful to man as well as environmental health. The adverse impacts of chemical insecticides on the animal and environmental health warranted the urgent need to switch over to some alternative control strategies, with a major focus on biological control. Being the most secure and safe mode ensuring the sound health of the environment as well as its biotic and abiotic components, biological control has attracted the attention of the scientific sector across the world. The success of any biocontrol programme depends on the correct identification of the potential natural enemy as well as its successful implementation in the pest infested field. In this regard, quite a good number of faunal ingredients with the major contribution by the arthropods have been identified as highly qualified based on the possession of several superb biological characteristics. The potential natural enemies of insect pests span

from unicellular organisms like the microbes to varied faunal groups represented by the invertebrate and vertebrate phyla. The invertebrate faunal groups with the potential for controlling insect pests are identified among the nematodes, insects as well as the arachnids, with the sole representation by the acari.

Members of the subclass Acari exhibit a constant association with insects, the types of relationship are exceedingly variable comprising symbiosis, commensalism, phoresy, and parasitism. Of these, the most common associations are considered as parasitism, symbiosis, or phoresy but in several instances, the exact nature of relationship remains largely unstudied, which formed the basic cause of the present investigation. In the present study, 29 species of insects of agricultural/horticultural relevance were surveyed across four districts of Kerala, viz., Thrissur, Palakkad, Malappuram and Kozhikode in order to record the mite associates as well as to conduct detailed studies on their nature of association. The results of the study unravelled the association of 65 species of mites with 24 species of insects, with a domination by members of Coleoptera, as 64% of the total mites collected were found associated with coleopteran members. Among the 64% of mites, the major representation (25 species) was made by the order Mesostigmata, followed by the orders Sarcoptiformes (10 species) and Trombidiformes (6 species). Such a high incidence of Mesostigmatid mites observed during the study seems to be in agreement with the earlier findings of Moser and Roton (1971) recording the association of 96 species of mites with the bark beetles, of which 45 species were members of the order Mesostigmata. Under Coleoptera, the rhinoceros beetle pest, *O. rhinoceros* was found to harbour the maximum number of mite species. In the present study, 13 species belonging to 13 genera and 11 families could be recovered from *O. rhinoceros*, and the species could be listed as *S. rhinocera* sp. nov., *U. heliocopridis*, *L. confusus*, *H. sardous*, *H. sammari*, *A. oryctae* sp. nov., *S. boharti*, *T. putrescentiae* from the adult, *H. stramenti*, *D. neodisetus*, *M. perglaber*, *Laelaps* sp. from its larval stages and *A. tariqi* from its eggs. The association of members of the mesostigmatid families like Laelapidae (*Laelaps* sp.) and Uropodidae (*U. heliocopridis*) with *O. rhinoceros*, as observed during the present study is in concordance with the earlier report of Hinckley (1967) on the association of the uropodid member, *Fuscouropoda* with the adults and the laelapid member, *Coleolaelaps* with the larval stages of *O. rhinoceros*. The deutonymphal stages of *Laelaps* sp. and *U. heliocopridis* were found to exhibit a

phoretic mode of association with the beetle host by establishing attachment with the latter by means of the anal pedicel as observed in the case of *U. heliocopridis*. This observation seems to support the findings of Binns (1982) and Hunter and Rosario (1988) who discussed the importance of anal pedicel in the establishment of phoretic relationship on respective insect hosts. The association of the members of the genus *Athogavia* of the family Canestriniidae with the beetle, *O. rhinoceros* observed during the current study supports the earlier report of Haitlinger (1989) on another species of the genus viz. *A. borneoica* harbored by the same host, *O. rhinoceros*. The author's report on the association of two more species of Canestriniidae viz. *A. tanzanica* and *A. gamana* with another member of *Oryctes* viz. *O. monoceros* further emphasise the constant association of the above two genera.

Members of the family Trigynaspidae like *Diplogynium oryctae* were already recorded as the associates of the beetle host, *O. rhinoceros* in South India (Vishnupriya and Mohanasundaram, 1988). The present observation on the association of a novel species of trigynaspid mite, *S. rhinocera* sp. nov. on the same host forms a further support on the habit of insect association of the family Trigynaspidae, since the first report of the genus *Schizodiplogynium* and the newspecies, *S. indicum* from the North Indian state like West Bengal from a habitat like rotten straw (Bhattacharyya, 1971). The present recovery of another novel species of *Schizodiplogynium* viz. *S. rhinocera* sp. nov. might be an indication of its association with some decaying material which later might have ascended on its beetle host, *O. rhinoceros* for a ride, as the latter being a constant associate with humus and decaying material to meet the purpose of oviposition.

Members of the genus *Hypoaspis* were already reported as associates of the beetle host, *O. rhinoceros* (Al-Deeb *et al.*, 2012; Gima, 2017) and the present study confirmed the constant occurrence of this acarine genus with the above host. The phoretic relationship between the adult females of *H. sardous* and *O. rhinoceros* helped to ascertain the association of acarine genus *Hypoaspis* with the insect genus *Oryctes* and thereby supporting the findings on the phoretic relationship of *H. rhinocerotis* on another species of *Oryctes* viz. *O. agamemnon* (Al-Deeb *et al.* 2012). However, no necromenic relationship could be observed between *S. boharti* and *O. rhinoceros* (Al-Deeb *et al.* 2012) though the authors observed *Sancassania* sp. exhibiting necromeny on *O. agamemnon*. Two species viz. *A. oryctae* sp. nov. and *T.*

putrescentiae were found to establish a parasitic relationship with their insect host . The former species was proved to exhibit an obligate parasitic relationship thereby enabling to establish parasitic nature of the members of the family Canestriniidae, thereby supporting the earlier findings that the members of the family could be obligate subelytral parasites of adult Coleopterans (O' Connor, 2009). Observations made on the predatory and parasitic habit of *T. putrescentiae* on the egg and adult stages of *O. rhinoceros* seems to be in agreement with several earlier other studies (Brust and House, 1988; Serpaet *al.*, 2004; Canevari *et al.* 2012) on predation and parasitism by the species on different species of insects.

The weevil host, *R. ferrugineus* was recognized as the second species next to *O. rhinoceros* in terms of the number of mite species harboured. Ten species of mites viz. *T. rhynchophora* sp. nov., *C. almerodai*, *U. assamomarginata*, *U. phoenicicola*, *U. javae*, *D. quadrisetus*, *Dinogamasus* sp., *M. krantzi*, *M. perglaber* and *C. keralensis* sp. nov. were found in association with *R. ferrugineus*. The incidence of species like *C. almerodai*, *U. assamomarginata* and *U. javae* and the genus *Macrocheles* on *R. ferrugineus* recorded during the study seems to be in agreement with the findings of Dilipkumar *et al.*(2015) from Malaysia. The phoretic association of *C. almerodai* on *R. ferrugineus* observed during the present study supports the earlier findings of Porcelli *et al.* (2009) on the presence of hyperphoretic fungi on the body of the mite, thereby pointing out the role of phoretic mites in the dispersal of fungal conidia. However, in the present study, no conidial spores were observed on the body of the phoretic mite species.

The results of the study disclosed the occurrence of deutonymphal stages of *C. keralensis* sp. nov. on the subelytral surface of *R. ferrugineus*. This observation is in complete agreement with the earlier report made by Al-Deeb *et al.* (2011) on the occurrence of the genus *Curculanoetus* on the subelytra of the same host. Occurrence of the first species of *Curculanoetus* viz. *C. rhynchophorus* was reported on another member of *Rhynchophorus* viz. *R. phoenicis* (Fain, 1974), and which formed the type species as well as the only species of the genus. The present new species, viz. *C. keralensis* sp. nov. forms the second addition to the genus and further suggests that the members of the genus *Curculanoetus* show close association with the members of the weevil genus *Rhynchophorus*. The present study also enabled to encounter a new species of Diplogyniidae, *T. rhynchophora* sp. nov. from the weevil genus

Rhynchophorus. The genus *Tridiplogynium* was first reported from a passalid beetle by Tragardh (1950) and the author could establish a wide host range for the genus on different members of Coleoptera.

Phoretic deutonymphs were found to establish attachment with their insect hosts by means of the anal pedicel. The presence of such an anal pedicel was evident in the deutonymphs of different of uropodine species like *C. almerodai*, *U. assamomarginata*, *U. phoenicicola*, *U. javae* which showed attachment with the cuticle of respective hosts by means of their anal pedicel. This observation is in agreement with the previous report of Moser (1976) on the deutonymphs of the uropodine species of the genus *Trichouropoda* which was found attached to the insect body via its anal pedicel. The anal pedicels often disclosed variability in their size and this was particularly specific in *C. almerodai* was found attached to under surface of the elytra of its insect host using a shorter anal pedicel whereas the remaining species, especially those which showed distribution on the exposed body parts using larger anal pedicels. These observations are in concordance with the findings made by Bajerlein and Witlanski (2014) that the pedicel length varied in the mite, *U. orbicularis* depending upon its distribution on different parts of the body of their host beetles. The present observation on the occurrence of the deutonymph of *C. almerodai* at concealed body parts like the undersurface of the elytra is in agreement with the finding of Porcelli *et al.* (2009). They found that the deutonymphs of *Uroobovella* were found mostly distributed on the exposed body parts like snout, leg and body appendages. Despite the above findings, authors like Ragusa *et al.* (2009) and Farahani *et al.* (2016) recorded the presence of deutonymphs of the genus *Uroobovella* on exposed body parts of insects rather than their subelytral surface. The observation made during the present study on the phoretic deutonymphs of *Curculanoetus* is in accordance with the findings of Al-Deeb *et al.* (2011). The previous reports on the distribution of *M. perglaber* and *M. krantzi* inhabitats like the soil and moss (Ozbek *et al.* 2015) could be supported during the present observation on the association of the above two species with the larvae of *R. ferrugineus*, since the larval stages of this pest show preference to colonise the decomposing plant matter.

The dung beetle, *C. repertus* formed the third coleopteran member in terms of the number of mite species harboured on its body parts. Five species of mites viz, *H.*

stramenti, *Poechilochirus* sp., *M. krantzi*, *H. subterranea* and *P. indicus* sp. nov. were found associated with the above dung beetle. Dung beetles like *O. philemon* and *C. molossus* were found to serve as hosts for three species of mites each, and the species recovered were *U. pilosetosa*, *M. glaber*, *H. zanzibarensis*, *Alliphis* sp., *H. heselhousei* and *P. foliata*. The association of the genus *Macrocheles* with *C. repertus* and *O. philemon* is in agreement with the results of the earlier studies of Takaku and Hartini (2001) which disclosed the occurrence of different species of *Macrocheles* on dung beetles of the genus *Onitis* and *C. repertus*. Their study could reveal the associations like *M. oigru* from *O. philemon* and *Onitis* sp., *M. kraepelini* from *O. falcatus* and *C. incertus*, *M. limue* from *Onitis* sp. The association of *M. krantzi* was already reported with dung beetle species like *Scarabaeus brahminus* and *S. erichsoni* (Evans, 1963). The present recovery of mite species like *M. glaber* from *C. lunaris* (Masan and Halliday, 2009) as well as *O. philemon* suggests that the above species of mite is a constant associate with different species of dung beetles, thereby supporting the findings of Ozbek *et al.* (2015) on the occurrence of *M. glaber* in soil and litter. The author remarked that the dung beetle, *O. philemon* shows constant association with soil arthropods. Although mite species like *H. stramenti* and *Poechilochirus* sp., and *H. zanzibarensis* formed the first report on dung beetles, their presence was already reported in soil and litter Hyatt (1987; Wise *et al.* 1988; Khaustov and Ermilov, 2018). The present observation on the association of the deutonymphs of *Alliphis* sp. on *C. molossus* closely agrees with previous reports (Masan and Halliday, 2009) on the recovery of four species of *Alliphis* viz. *A. halleri*, *A. montanus*, *A. phoreticus* and *A. scarabaeorum* with different species of dung beetles. The present result also serves to support the observation made by Bahrami *et al.* (2011) on the association of the deutonymph of *Alliphis* sp. with *Euonthophagus gibbosus*. Thus the study helped to confirm a wide spectrum association of the members of the genus *Alliphis* with different species of dung beetles. The present incidence of *Pavania foliata* of the family Dolichocybidae on the dung beetle, *C. molossus* is in agreement with earlier report of Khaustov and Frolov (2020) on its association with the dung beetle, *Scarabaeus typhon*. Members of the genus *Pavania*, were known to exploit different species of dung beetles as their hosts as observed in the case of *P. lanceolata* on *S. Pius* (Bahramian *et al.*, 2015), *P. neotropica* on *Canthon histrio* (Khaustov & Frolov, 2017), *P. khiavensis* on *Euoniticellus fulvus* (Sobhi *et al.*, 2017), *P. Africana* on

Frankenbergerius gomesi (Khaustov & Frolov, 2018 b), thereby implying this genus *Pavania* as constant associate of insects like the dung beetles.

The coleopteran member, *B. rufomaculata* harboured three species of mites viz. *U. orbicularis*, *N. gratum* and *C. batocera* sp. nov. The occurrence of the Canestriniidae member, *C. batocera* sp. nov. on this insect is in agreement with the earlier record on the association of another member of the family Canestriniidae viz. *Grandiella batocerae* with *B. rufomaculata* (Vishnupriya and Mohanasundaram, 1988). Various species of the genus *Canestriniella* were reported to establish a close association with *Batocera* as evidenced through the findings of Berlese (1910) disclosing the association between *C. amplexans* and *Batocera hector* and *C. togata* with *B. lunata* as well as Haitlinger (1995) on *C. phoebinae* with *B. albofasciata*. The association of the species, *N. gratum* with *B. rufomaculata* observed in the present study and the previous report of *N. gratum* with carrion beetle suggest a broad spectrum association of the former species with members of Coleoptera. The present study also helped to record the association between *U. orbicularis* and *B. rufomaculata*. This supports the earlier findings on the association of the species with coleopteran members like *R. ferrugineus* and coprophilous beetles (Al-Deeb, 2011; Bajerlein and Bloszyk, 2004; Bajerlein, 2011), thereby affirming its broad host range on insects, especially the most diverse group of insects like the Coleoptera.

The remaining species of coleopterans examined during the study such as *A. foveicollis*, *A. frontalis*, *C. sordidus*, *O. longicollis*, *H. vigintioctopunctata*, *H. unicolor*, *X. globosa*, *Altica* sp., *Gonocephalus* sp. 1 and 2 were not found supporting a rich fauna of Acari as they harboured either one or two species of mites. The study revealed *H. sammari* as a common associate of beetles like *A. foveicollis* and *A. frontalis*. The association of the species with termite nests of camphor tree as already recorded (Eraky, 1999 b) and the present detection of the species on beetle hosts disclosed the ability of *H. sammari* to exploit members of different orders of insects as its hosts. The mite species, *C. glossinae* was found associated with the beetle, *H. vigintioctopunctata* as evidenced during the present study. The species has a previous phoretic record on dipterans (Fain and Elsen, 1971) and the present study serves to extend its host range to coleopterans also. The study also disclosed a member of Histiotomatidae, belonging to the genus *Histiostoma* (species identification could not be done) with chrysomelid beetles, thereby supporting the previous records on the

association between Histiotomatidae and Chrysomelidae as observed in the case of *Lema nigripes* (Santiago-Blay and Fain, 1994).

During the present study, species like *M. muscaedomesticae* could be recovered from weevil pests of banana such as *O. longicollis* and *C. sordidus*, the latter two species showed strong affinity towards the banana pseudostem. Earlier records on the association of *M. muscaedomesticae* clearly revealed its distribution on insect hosts like dung beetles, carrion beetles, flies, as well as other habitats like litter, manure, poultry food and compost (Takaku *et al.*, 2012), thereby attributing a wide range of habitats and life styles for the species. The present detection of the phoretic habit of the species on banana pests like *O. longicollis* and *C. sordidus* also can justify its ability to enjoy the habitats available in the decomposing banana and subsequent transportation to new and favourable microenvironment through phoretic transportation via the carrier insects like the banana weevils mentioned above. A similar mode of life style could be attributed to *H. furrowa* sp. nov. also which was found phoretic on *O. longicollis* and *C. sordidus*, as observed during the study. The members of Histiotomatidae are the common inhabitants of varied habitats like the soil, litter samples, decaying vegetables and fruits, manure, dunghills as well as insect hosts (Eraky, 2000 b; Tagami and Kuwahara, 2005; Pernek *et al.* 2012). Therefore, banana pseudostem also could serve as an excellent substratum for the survival of the phoretic mite species like *H. furrowa* sp. nov. and the insect pests dwelling in the pseudostem would serve as vehicles for their transport. Further, the study also disclosed that *H. furrowa* sp. nov. was the only species showing necromenic habit on its insect host, *O. longicollis*. The necromenic habit of the species could be correctly assigned the facultative necromeny in which the carcass of the weevil was not obligatory for the subsequent development of the deutonymph (Bhadran and Ramani, 2019). This observation seems to be in agreement with the earlier reports on the necromenic habit of the genus *Histiostoma* such as *H. polypore* on its host, *Forficula auricularia* (Wirth, 2009). The deutonymphs of *H. furrowa* sp. nov. were found to get attached to the body of their weevil host, where they remained there until certain cues of unknown nature triggered their detachment from the body of carrier weevils and subsequently moulted to the tritonymphal stage. As the progressive development of the species was found possible on all substrates, including the beetle cadavers, the particular necromenic habit of the species observed during the study could be

considered as facultative, thereby contradicting the earlier report (Wirth, 2009) in which the smaller phoretic animal remained attached to the host until it died, and then it started feeding on its cadaver. In the above study, the deutonymphs of *Histiostoma* were found feeding only on the dead nymphs of earwigs, and then getting attached to the later stage nymphs which survived in the earwig's brood.

The present study enabled to record the association of species like *U. shangaica* on the host insect, *X. globosa*. *U. shangaica* was previously recorded from a coleopteran host such as an unidentified species of *Coprini* sp. (Wisniewski and Hirschmann, 1996). The present detection of *U. shangaica* on *X. globosa* indicates its broad propensity to enjoy dispersal on different members of Coleoptera. The present study disclosed the phoretic habit of *H. longispinus* on *Gonocephalus* sp. 2 collected from a paddy field. Presently, no data available on the distribution records of the species on insect hosts, and the only record of the mite species was from the moss and rotten wood samples (Atyeo and Baker, 1964). Hence the distribution of *H. longispinus* on the coleopteran, *Gonocephalus* sp.2 observed during the present study might have occurred from the manure accumulated in the paddy field. The predatory mite, *C. kuznetsovi* found associated with *Gonocephalus* sp. 1, in the present study was reported earlier from samples of soil-litter, and also stored products (Bochkov and Khaustov, 1999). Therefore, it may be speculated that the mite specimens loaded on the insect host, *Gonocephalus* sp., an inhabitant of rotten wood for a free ride.

Over 13% of the total mite species collected during the study from the various insect hosts screened, could be seen in association with different plants like chilli, brinjal and spinach infested with the notorious whitefly pest, *B. tabaci* and all of them were found to be predatory in nature. Of these, one species of phytoseiid predator, *A. largoensis* was found associated with two species viz. both *B. tabaci* and *A. floccosus*. The co-incidence of *A. largoensis* with whiteflies observed during the present study is in support of the earlier findings to attest the species as a potential agent in effectively suppressing the population of *B. tabaci* (Cavalcante *et al.*, 2015) and the giant whitefly, *Aleurodicus cocoi* sinfesting cashew (De Alfaia *et al.*, 2018). Various other species of genus *Amblyseius* viz. *A. aleyrodis*, *A. swirskii* and *A. cucumeris* were also reported to be predatory on whiteflies. Of these, *A. aleyrodis* was proved to be an effective biocontrol agent of the cotton whitefly, *B. tabaci* (Elbadry, (1967) while *A. swirskii* was recognized as a potential species in controlling two species of whiteflies

viz. *Trialeurodes vaporariorum* and *B. tabaci* (Blockmans *et al.*, 2005) and *A. cucumeris* exerted commentable suppression of whitefly population under field condition (Stansly and Castillo, 2009). While pooling together all the above observations including the present results, it can be concluded undoubtedly that the members of *Amblyseius* are excellent agents in controlling white flies.

The present study helped to record the incidence of phytoseiid species like *E. ovalis* on plants infested with *B. tabaci* thereby supporting the results of earlier studies made by Borah and Rai (1989) revealing the ability of the species to predate as well as reproduce on a diet of *B. tabaci*, and Messelink (2008) on the role of *E. ovalis* to suppress the population of *B. tabaci* on greenhouse cucumber crops. Some other members of *Euseius* like *E. rubini*, *E. scutalis* and *E. concordis* were also found feeding on different species of whitefly, thereby agreeing with the results gathered by Elbadry (1967) and Teich (1966) on the effective suppression brought out by *E. rubini* on *B. tabaci* population. The potential of *E. scutalis* in controlling the population of *B. tabaci* on greenhouse cucumbers was also reported (Nomikou *et al.*, 2002) and the present observation serves to ascertain the predatory habit of the above species. The biocontrol potential of other species of *Euseius* viz. *E. rubini* was confirmed on all stages of *Parabemisia myricae* (Wysoki and Cohen, 1983) and *E. concordis* in suppressing the whitefly population of *A. cocois* (De Alfaia *et al.*, 2018) was also known and the present study supports the above findings. All the above studies thus clearly proved the wide prey range of the members of the genus *Euseius*. The occurrence of species viz. *A. channabasavannai*, *A. vasiformis*, *E. finlandicus*, *T. kroeffis*, L. (L.) *moolamkudensis* sp. nov., *C. anomala* and *C. heterostriata* observed during the present study forms new records on whiteflies and helps to confirm the predatory status of the above species on different species like *B. tabaci* and *A. floccosus*.

The order Blattodea was found to comprise 14% of the total mite species collected during the study. Presently, several species of mites were recorded earlier from termites, most of the host termite species were found to be unidentified so far. The present study enabled to recover 10 species of mites from three species of termites, all of which formed new host records. The mite species, *R. vicantus* recovered during the study from termite species like *O. feae* and *O. obesus* were recorded earlier from soil litter and plant materials (Barbosa and De Moraes, 2020). Similarly, mite species

like *H. herballi* observed as phoretic on *O. obesus* during the present study was previously reported from soil samples (Eraky *et al.*, 2017). The above two records helped to conclude that mites present in the soil and litter samples might have loaded on the species of termites for dispersal to new habitats. The phoretic habit of *A. solimani* on *N. gardneri* observed during the present study is in agreement with the earlier finding on the association of *A. solimani* with an unidentified species of termite (Eraky, 1999a). The present observation on the association of the members of the acarine genera such as like *Schweibea*, *Acotyledon*, *Caloglyphus* and *Sancassania* with termites is in agreement with earlier reports (O' Connor, 2001; Eraky *et al.*, 2015). However, the association of the species, *P. paramaevi* with the termite species, *O. feae* recorded during the present study seems to contradict the earlier findings on the occurrence of the above species on the beetle species, *Lucanus ibericus* (Hosseininaveh, 2015). Thus, the results of the present study helped to draw the conclusion that *P. paramaevi* enjoy distribution not only on termite hosts but also on the most diverse insect order such as the Coleoptera.

Out of the total species of mites collected from insect hosts, 8% were recovered from two species of orthopteran pests viz. *O. chinensis* and *O. hyla*. examined during the study. All the mite species viz. *L. chinensis* sp. nov., *L. treati*, *N. mapuche*, *P. palappuramensis* sp. nov. and *S. brasiliensis* associated with the hosts, *O. chinensis* and *O. hyla* formed new host record, thereby indicating the need to undertake detailed exploration of orthopteran members so as to identify more number of mite taxa including novel taxa from an agricultural state like Kerala . The genera of parasitic mites such as *Locustacarus*, *Podapolipus* and *Leptus* were already reported to be the associates of different members of Orthoptera and a novel species of *Podapolipus* viz. *P. nitidulae* was already described from the South Indian state like Tamil Nadu (Ramaraju and Mohanasundaram 1996) as an associate on *O. nitidula*. Several unknown species of *Locustacarus* and *Podapolipus* were found parasitic on *O. nitidula* in India (Sarangi *et al.* 2010) and species like *P. husbandi* was also reported from India, to be associated with an unknown species of *Oxya* (Sarangi *et al.*, 2012). The parasitic habit of a novel species of *Podapolipus*, *P. gryllacridi* on the cricket, *Chaulio gryllacris* was also reported from Australia (Lindquist and Sidorchuk, 2019). The present observation on the association of a new species of *Podapolipus*, viz. *P. palappuramensis* sp. nov. on *O. hyla* forms a new host record and it gives further

support on earlier findings on the incidence of genus *Podapolipus* on different species of orthopterans in India as well as abroad. Members of the genus *Podapolipus* were known to infest insect hosts other than orthopterans, like the cockroaches which were found to serve as hosts for species like *P. platyzosteriae* (Husband, 1986). The ectoparasitic association exhibited by *P. palappuramensis* sp. nov. as well as the occurrence of large adult females on the exposed body parts like the abdominal tergites and thorax is in agreement with the earlier findings of Ramaraju *et al.* (1998) on the Indian species, *Podapolipus* sp. infesting the dermestid beetle, *Dermestes ater*. The above observations clearly attest the wide host range of the members of the genus *Podapolipus* on insect hosts belonging to different orders.

The present study enabled to record the association of members of *Locustacarus*, including a novel species on the orthopteran pest, *O. hyla*. The genus *Locustacarus* has gained attention as intratracheal parasites of bumblebees and grasshoppers (Rahmatzaei *et al.*, 2021) and the authors described four species including a new species of *Locustacarus*, viz. *L. aiolopi*, the latter infesting the grasshopper, *Aiolopus thalassinus*. Of the four species of *Locustacarus* described by the above authors, *L. buchneri* was the only species which showed exclusive association with bees, and the other three species, viz. *L. aiolopi*, *L. masoni* and *L. trachealis* were found in association with different species of the family Acrididae. The present observation on the association of a new species of *Locustacarus* supports the earlier observation on the association of the members of above genus with orthopteran hosts. The study also disclosed the ectoparasitic nature of an erythraeid member viz. *Leptus treati* on the grass hopper species like *O. chinensis* and *O. hyla*. This finding is in support of the earlier report of Haitlinger (2002) on the ectoparasitic habits of a species belonging to *Leptus* viz. *L. laviniacus* on two species of *Oxya*, viz., *O. nitidula* and *Oxya* sp. The parasitic species of Trombidiformes mites recovered during the present study showed some parasitic adaptations. For instance, the adult female of *P. palappuramensis* sp. nov. was characterised by the presence of reduced number of legs, limiting to one and modified mouthparts to cling to the host's body. Further, their gnathosoma was reduced and idiosoma was found enlarged considerably so as to accommodate the maximum number of eggs. These character combinations of the parasitic females of the species observed in the species collected during the study are in line with the previous observations on other species of the genus like *P. womersleyi*, *P.*

platyzosteriae, *P. pacificus*, *P. haramotoi*, *P. monistriae* recovered from both coleopterans and orthopterans (Husband, 1986). The potential of the species of the genus to lead a successful parasitic life style is therefore confirmed during the study.

During the present study, only a single species of mite could be collected from the lepidopteran insects examined. The lepidopteran host which disclosed the association of mites was the paddy pest, *M. leda ismene* and the mite species collected was *A. halleri*. The genus *Alliphis* was proved to show association with lepidopterans like *Delias eucharis*, *Pachliopta* sp. and *Cepora nerissa* (Sarangi, 2014). The presence of *A. halleri* on other hosts like the dung beetles as well in habitats like leaf compost was also recorded earlier (Halliday, 2008). The above observation indicates the adaptability of the species to enjoy varied pattern of distribution.

Among the varied types of association met with between the insects and mites, 76% was rated as phoretic association on respective insect hosts. While some of the R-selected mite species like the eriophyoids largely depend on air currents to enjoy successful dispersal, other K-selected mite species rely mostly on a phoretic mode of dispersal (Krantz, 2009). Hence it could be assumed that the primary association established by mites with arthropods is phoresy, in order to ensure successful dispersal. The phoronts employ various means of attachment to establish firm attachment with their hosts and in the present study, the deutonymphs were found attached to their hosts using their anal pedicel whereas the anal sucker was used as the attachment organ by the astigmatine deutonymphs. The results of the study disclosed that majority of phoretic mites were members of the acarine families like Uropodidae, Dinychiidae, Histiostomatidae, Hemisarcoptidae, Winterschmidtidae, Acaridae and Suidasiidae. In the remaining cases, no specialised structures were visible among the phoretic mites. The presence of anal pedicel observed in the phoretic deutonymphs of Uropodidae serves to support the earlier observations made in the fossils of Baltic amber (Dunlop *et al.*, 2013) on the presence of anal pedicel in deutonymphs of *Uroobovella* which enjoyed phoretic dispersal on longhorn beetles. The anal pedicel was reported to develop as a secretion from the gland which open into the anus and later become which hardened and used to secure attachment of mites onto the cuticle and whose length shows variation depending upon the sites of attachment (Bajerlein and Witlanski, 2014). The structural diversity of the attachment organs met with among the different uropodines was discussed in detail (Bajerlein *et al.*, 2013).

Unlike the mesostigmatid deutonymphs, the astigmatid deutonymphs collected during the present study were found to possess a specialised developmental stage to help phoretic dispersal which is called the ‘hypopus’ stage. This stage is known as the most outstanding stage of development in free living Astigmata (Corente and Knulle, 2003). It is a facultative phase between the pronymph and tritonymph and the development of which is determined in the late larval and early protonymphal stage (Stratil and Knulle, 1985). As observed in the present study, the hypopus exhibits several morphological adaptations and highly regressive morphology (Smiley, 1991; O’Connor, 2009). The hypopi were found to possess adoro-ventrally flattened, sclerotised body, reduced mouthparts, adhesive anal suckers and legs with foliate setae for keeping in contact with their hosts as reported in many families of Astigmata. All members of Histiostomatidae collected during the present study were recovered in the hypopial stage, thereby confirming the earlier findings (Fain *et al.* 1993; Ashfaq and Sarwar, 2001; Sokolov *et al.*, 2003; Negm *et al.*, 2011; Bhadran and Ramani, 2017; Pereira *et al.*, 2018) that only the deutonymphal stages of the histiostomatid mites could be collected from their respective hosts. Under the family Acaridae, all the members except *T. putrescentiae* exhibited phoresy and were in their hypopus stage, thereby supporting the earlier studies (Fain and Philips, 1983; Nesbitt, 1988; Fain *et al.*, 1999; Negm *et al.*, 2011; Silva *et al.*, 2016; Silva *et al.*, 2020). The high incidence of acarine phoronts belonging to Sarcoptiformes and Mesostigmata observed during the present study could be due to the phoretic adaptations exhibited by them.

A single species each could be recovered during the study under the acarine families Hemisarcoptidae, Winterschmidtidae and Suidasiidae and all the collected specimens were in their hypopal stage. This observation thereby supports the previous records (O’Connor and Houck, 1989) on the deutonymphs of hemisarcoptid members, viz, *Superioropushuron montanus* and *Huronopus michiganensis* phoretic on insects like *Exeristes comstockii* and *Neoxorides pillulus* respectively. Similar findings exist on coccinellid beetles also as in the case of *Calviaduo decimguttata* which hosted the hypopus stage of *Divilia exigua* (Fain *et al.*, 1997). The present study disclosed the phoretic habit of a species belonging to the family Winterschmidtidae, viz. *Procalvolia* sp. on beetle hosts like *A. foveicollis*, *H. unicolor*. In the above species, phoresy could be assigned solely to the hypopus stage and no other stages could be

collected in any instance. This finding serves to support the earlier findings of various authorities (Fain and Mason, 1989; Ramaraju and Mohanasundaram, 1998; Okabe and Masino, 2003), ascertaining the phoretic dispersal of the species through the hypopus stage.

The present study disclosed variations in the site preference exhibited by the mite associates on the body parts of their respective hosts. Accordingly, the distribution pattern as well as population density of individual species of mite on respective insect host also showed considerable variation. It was observed that 17% of mite species preferred to colonise the abdominal segments of their insect hosts. Thus the abdominal region was recognized as the most preferred site for distribution of the mite associates and the phoretic load of mites was also found high on the abdomen. The second preference was given to the subelytral surface and hindwings and thereby agreeing with the observations made by Moser (1976) who recorded 99.6% of the mites preferred subelytra and Al-Deeb *et al.* (2011) who observed large number of phoretic mites under the elytra of *R. ferrugineus*. The abdominal as well as subelytral area preference shown by the mite associates recovered during the present study coincides with the previous findings of Al-Deeb *et al.* (2012) which recorded majority of mites under the elytra and the abdominal tergites. The selection of abdominal tergites and subelytral surface for colonization by mites could be accounted for their cryptic nature and habit of becoming concealed themselves on hidden areas of the body of insect hosts so as to ensure protection from desiccation due to exposure to extreme climatic conditions as well as to prevent dislodging during the mobility/flight of the insect hosts insects (Dilipkumar *et al.*, 2015). The chances of dislodgement from host's body increases for those species of mites which lack any device/attachment organ/modifications to aid their phoretic dispersal while those with specific phoretic adaptations like an attachment organ such as anal pedicel or anal sucker would be escaped from dislodgement. The incidence of some phoretic uropodine mites on leg segments and snout observed during the present study are the suitable examples for this. Uropodine members like *U. marginata* showed distribution on exposed body parts like the legs, thorax, head and snout of its beetle host, *R. ferrugineus* (Mesbah *et al.*, 2008; Porcelli *et al.*, 2009; Farahani *et al.*, 2016) and they enjoy successful dispersal without getting dislodged from the body of their insect hosts.

Development of specific phoretic adaptations was shown by many phoretic species as observed during the study. The adaptive features are the anal pedicel as well as anal suckers. The anal pedicels are adhesive structures, developed as secretion by the anal gland and upon hardening they ensure firm grip on the cuticle of host insects thereby securing the mite species from getting dislodged during the flight movement of the hosts. Same is the case with the deutonymphal stages of the Sarcoptiformes mites recovered during the study. The deutonymphs of these mites were found to possess well developed suckers at their anal region which could be successfully used for attachment on the body of the insect hosts. Even with these modified structures, some of the Sarcoptiformes mites collected during the present study viz., *H. furrowa* sp. nov., *C. keralensis* sp. nov. and the Uropodine mites like *C. almerodai* and *U. orbicularis* preferred to get attached to the under surface of the elytra and hindwings of their respective insect hosts. The high incidence of *C. almerodai* on the subelytral surface is in agreement with previous reports (Porcelli *et al.*, 2009); Farahani *et al.*, 2016). Species like *Histiostoma* sp. showed high incidence in sites like the mesosternal groove and subelytral surface of its beetle host, *O. longicollis* (Bhadran and Ramani, 2019) thereby justifying the cryptic pattern of distribution of mites in least exposed areas on the weevil body. It was also observed that the some ectoparasitic novel mite species recovered during the current study viz. *A. oryctae* sp. nov., *P. palappuramensis* sp. nov. and *L. chinensis* sp. nov. exhibited more preference to occupy on the abdominal segments than the subelytral surface and hindwings. Such distributional preference might be an adaptation to avoid the chances of dislodgment during the flight movements of their insect hosts. Also, the abdomen also could serve as an excellent substratum to be exploited by the parasitic species for deriving haemolymph from their host.

Though the number of mite species distributed on the head region of insect hosts was found high (13%), the phoretic load on the head was very low. Majority of the species which occupied the head region were found phoretic on different species of termites. The limited space available on the head capsule of termite hosts would be quite inadequate to accommodate more number of mite associates and probably, this would be the reason for the low phoretic load on the head region, observed during the present study. The present study also helped to record the incidence of phoretic mites on the other body parts like prosternum, mesosternum, mesoventrite, metaventrite and

hypomeron and which were not reported as the distribution sites for mites, in any of the earlier studies so far. The Sarcoptiformes and uropodine deutonymphs colonising such exposed areas mentioned above were found to enjoy a secure attachment themselves on the body of respective insect hosts via the anal suckers / anal pedicel. However, species like *Hypoaspis* and *Dinogamasus* were found to enjoy secure dispersal by colonising the exposed body parts of their insect hosts and without any specialised modification/ attachment device and the detailed mechanism of their phoretic dispersal needs further investigation.

The mite association was comparatively very rare on lepidopteran hosts, as revealed through the present study. The only species recovered from a lepidopteran member was *A.halleri* and which was found colonising under the proboscis of the paddy butterfly, *M. leda ismene*. This finding is in concordance with earlier observation (Sarangi *et al.*, 2010) on the recovery of phoretic mites like *Alliphis* sp., *Eviphis* sp., *Proctolaelaps* sp., etc. which colonised under the proboscis of their lepidopteran hosts. The mites are free to make easy ascending and descending movements via the proboscis when the insects extend their proboscis for feeding. Also the proboscis can provide a concealed area where the mites can colonise very securely. These would be the probable reasons for the selection of the undersurface of the proboscis of lepidopteran hosts by their mite associates, though many parasitic mites were reported to prefer other body parts like the tympanic membrane, dorsum of thorax, ear and abdomen (Treat, 1954; Treat, 1955; Treat, 1966; Treat, 1969) of lepidopterans.

B. Impact of phoretic mite load on selected species of insect hosts

During the study, it was noted that the phoretic load on certain coleopteran hosts exceeded in such a way that the body weight of the host with mites varied significantly when compared to the body weight without mites. Such a significant variation was observed in three species of insects, viz., *O. longicollis*, *R. ferrugineus* and *O. rhinoceros*, all of which harboured exceedingly high number of mites on their body and hence were selected for detailed studies. It was also seen that the number of mites and the body weight difference of the hosts shared a positive correlation, indicating that their body weight increased considerably as the number of mites increased. The mean body weight of *O. longicollis*, *R. ferrugineus* and *O. rhinoceros* with phoretic mites could be recorded as 125.27 ± 3.99 , 1829.8 ± 19.21 and 1017.70 ± 29.21

respectively and which got reduced to 121.35 ± 4.02 , 1807.40 ± 19.57 and 974.30 ± 27.48 after the removal of mites. The body weight difference with the mites and without mites (after the removal of mites) was found to be statistically significant. A high phoretic load of mite would impede the flight take-off capability of the hosts as revealed through previous studies as observed in *Musca domestica* due to the phoretic load of the histiostomatid hypopi (Elzinga and Broce, 1988). Similarly, a reduction in the flight take-off capability of *R. dominica* was recorded when the phoretic load of its mite associate, *Acarophenax lacunatus* got increased (Rocha *et al.*, 2009). Such a reduction in the flight ability of the host of then resulted in significant variation in the height of attack on host trees (Kinn and Witcosky, 1988). The reduction in flight efficiency was also recorded in *R. ferrugineus* also (Al-Deeb *et al.*, 2011) owing to phoretic mite load. However, in the present study, the flight take-off ability of host beetles were not tested, though significant variation was recorded in the body weight of insect mite hosts owing the phoretic mite load. Of the hosts studied, the beetle, *O. longicollis* was not recognized as a strong flier and instead it spent most of the time inside the pseudostem. Therefore, an increase in the phoretic load might not have a very large impact on the host beetle. This is true in the case of *R. ferrugineus* also, which was found to follow lifecycle in concealed habitats. Since the breeding takes place inside the host trees, the weevils do not undertake a long flight. In the case of *O. rhinoceros*, the adult beetles take flights to the breeding grounds like manure heaps and organic materials to lay eggs (Bedford, 1976). A reduction in flight ability thus can hamper the breeding process. Since in the present study, *O. rhinoceros* was collected through light trap and pheromone trap apart from direct handpicking, it can be assumed that the above phoretic load would not have exerted a direct impact on the flight take-off ability of the host.

Apart from the flight take-off ability, phoretic mites are known to affect the longevity of the hosts as observed in the case of phoretic mites associated with *Onthophagus binodis* (Kotiaho and Simmons, 2001) and *R. ferrugineus* (Mazza *et al.*, 2011). In cases, a high phoretic load was found to reduce the host longevity. It was also reported that a high phoretic load can affect the olfactory response of the host. It was reported that the plum curculio, *Conotrachelus nenuphar* harbouring more number of phoretic deutonymphs of *Histiostoma* showed little response to the normally attractive synthetic odours (Houck *et al.*, 2013). The present observation that the high phoretic

load could significantly affect the body weight of host beetles thus warrants further studies to trace their impact on the host longevity and behavior.

C. Mite-host relationship and life cycle parameters of *Histiostoma furrowa* sp. nov., a phoretic species exhibiting facultative necromeny on the banana pseudostem weevil, *Odoiporus longicollis*

During the study, it was observed that the deutonymph of *H. furrowa* sp. nov. molted into successive stages when placed on different culture media like yeast solution, banana pseudostem and weevil carcass. The deutonymph while molting into the tritonymph on the culture medium comprised of the carcass of its weevil host, exhibited necromeny, as the latter was defined (Schulte, 1989) as a type of interaction in which the necromenic organism climbs over the carrier organism when it is alive and complete its life cycle after the carrier's death. The dislodgement of about half the number of deutonymphs from the weevil carcass to the pseudostem further helped to ascertain the occurrence of necromeny. This observation thus revealed that the necromenic life style could be of the facultative type and not the obligatory type. The obligatory type of necromeny as reported by Wirth (2009), is the relationship where the phoront would get attached to the host earwig until its death and resumed development on its cadaver. The phoretic hypopi could develop exclusively on the host cadaver and hence the author called the relationship as 'obligatory necromeny.' In the present study, the deutonymphs molted into tritonymphs not only on the beetle cadaver, but also on other media like the banana pseudostem and yeast solution. Also, when the cadaver and pseudostem were placed together, about half of them were dislodged from the weevil to resume subsequent development on the pseudostem. The relationship of the species as observed during the present study was found extended beyond phoresy, as the latter does not involve further development of the organism (White *et al.*, 2017). The type of the relationship exhibited by *H. furrowa* sp. nov. with its weevil host, *O. longicollis* thus could be designated as facultative necromeny.

The filter paper placed on yeast solution would serve as an excellent culture substratum supporting the development of histiostomatid mites, since their mouthparts are highly specialized for filtering and channeling the micro-organisms and particulates in to the buccal cavity (Evans, 1999; O' Connor, 2009). The ability of the deutonymphs to develop into adult stage within 3 days as observed during the

present study showcases the ability of the species to establish itself when suitable condition arises. Also it was noted that some of the deutonymphs remained as such without further molting for about one month even under similar conditions. The exact reason for this high disparity in the duration of deutonymphs to molt into tritonymphs under similar condition could not be traced during the study and warrants further investigation.

Mate guarding exhibited by *H. furrowa* sp. nov. has already been reported in other members of the family Histiotomatidae (Kruger and Wirth, 2011). The species was also found to exhibit precopulatory guarding, in which the immature female in its tritonymphal stage was guarded by male. This observation seems to be in support of the earlier observation made on other species of *Histiostoma* such as *H. feroiarum* (Liana, 2005). Further, the females of *H. furrowa* sp. nov. were found to exhibit polyandry and which could have evolved as a fitness advantage. This condition would favour the males with high fertilization efficiency during the course of evolution and it is hypothesized as 'sperm sexual selection' (Keller and Reeve, 1995). The condition of polyandry is also reported in other species of mites. Konior *et al.* (2001) reported increased fecundity in the bulb mite offsprings of females which were allowed to mate with multiple males. Polyandry can also reduce the female fitness in many ways as mentioned in a review (Stockley, 1997), and which inturn would lead to sexual conflict, finally giving rise to an evolutionary arms race for co-evolution of both male and female sexual strategies. The arrhenotoky exhibited during parthogenetic reproduction as well as the 1:1 sex ratio is common in many species of Histiotomatidae (Kruger and Wirth, 2011).

Chapter 6

Introduction

Insect-mite interactions have been well documented from various perspectives based on their ecological, evolutionary and biological control relevance, in the context that mites can exert major impacts on insect populations by exhibiting a multiple range of symbiotic associations like phoresy, mutualism, commensalism, parasitism and inquilinism (Okabe, 2013). The mutualistic associations between mites and insects have been quantified (Wilson and Knollenberg, 1987; Okabe and Makino, 2008), and their parasitic/ predatory associations have been elucidated against varied groups of insect pests of agriculture (Gerson and Smiley, 1990). Of these, the latter aspect forms the subject matter of the present part of the thesis by focusing on the elucidation of the parasitic as well as predatory impacts of mite associates in relation to biological control of respective insect hosts.

Biological control, being the most effective method in restoring biological system without making any harmful interference of chemicals, has attracted the attention of both ecologists and agriculturists and it is the only feasible way to suppress an invasive species over a large area. This strategy of pest control aims to induce a permanent ecological change in favour of the natural enemy complex, thereby ascertaining the suppression of pest populations in affordable levels. By targeting on strengthening of the food web of nature further, there is no wonder that biological method of pest control has become an important component of integrated pest control programmes. Statistics reveal an ample number of species list suppressed by natural enemies in the past century to be 200 species of invasive insects and 40 species of weeds around the world (Van Driesche *et al.*, 2009). Though the name biological control highlights the ‘natural method’, this approach involves an active human role.

Insects are known to possess a wide array of natural enemy complex, comprised of various groups such as predators, parasites, parasitoids and pathogens. The predators are free living organisms that can devour a large number of preys during their lifetime. Parasites and parasitoids benefit at the expense of the host, the former do not usually kill the host whereas in the latter case, the young ones usually kill their host. Pathogens

are disease causing organisms that can either kill the host or reduce its viability. There are different approaches in biological control that was evolved through years of failure and success stories. Classical biological control was the first type which makes use of imported natural enemies to control an invasive pest. Inundative biological control relies on the mass culturing of natural enemies while conservation biological control seeks to suppress the pest population by manipulating the environment so as to enhance the existing natural enemy population.

The use of Acari in biological control explores the diverse types of their activities such as parasitism, parasitoidism, competition, disease transmission and predation for the control of insect pests. There are three basic strategies in using mites for biological control, as for any other natural enemy; importation, conservation and augmentation. The first step intends to create a stable association between the predator and prey brought about by the inoculative release of the predator. Conservation refers to eliminating any environmental factors that are adversely affecting the predator. Augmentation is the manipulation of predator population by repeated releases. The most important component in the biological control of any organism is the identification of its natural enemy in its habitat. This is advantageous in that the natural enemy thus takes no time to get acclimatised to the surrounding.

The members of acarine families like Macrochelidae, Uropodidae and Parasitidae have been used for the last so many decades as efficient biocontrol agents against household pests like houseflies (Axtell, 1963). The biocontrol potential of various families of mites is being investigated for the past 30 years and more than a dozen acarine families are employed for this purpose (Gerson and Smiley, 1990). The Acarine predators and parasites of insects are commonly found in families like Acaridae, Acarophenacidae, Anystidae, Arrenuridae, Ascidae, Bdellidae, Camerobiidae, Ceratozetidae, Cheyletidae, Cunaxidae, Ereyetidae, Erythraeidae, Eupalopsellidae, Galumnidae, Hemisarcopidae, Hydryphantidae, Laelapidae, Limnesiidae, Macrochelidae, Parasitidae, Phytoseiidae, Tarsonemidae and Trombidiidae as listed by Gerson *et al.* (2003). The mesostigmatid family Phytoseiidae is the most widely studied family since its members exhibit broad spectrum predation over a wide range of insects and mites. Parasitic acarines may be ectoparasitic or endoparasitic on insects. The ectoparasitic mites of some families in terrestrial and aquatic Parasitengonina exhibit predatory stage thereby exhibiting dual life strategies

in its life cycle (Welbourn, 1983) while the mites in the family Podapolipidae display parasitism throughout the post-embyonic stage (Krantz, 2009). The parasitic mites might exhibit some morphological modification and specialisation which include hooked or needle like chelicerae as exhibited by some Erythraeidae and Trombidiidae. The members of order Orthoptera are mainly parasitized by Podapolipidae and Erythraeidae. Most of these parasitic interactions are highly specific in nature.

The benefits of using predatory acarines are many; as they do not cause phytotoxicity, they reduce the need for application of acaricides, they can disperse their own and increase their population over time (Gulati, 2012). In case of beneficial species like that of honeybees, infestation of parasitic mites can reduce the pollinating behaviour. The members of order Lepidoptera are largely infested by parasitic mites as reviewed by Treat (1975). Besides the predatory and parasitic association between mites and insects, the phoretic mites in exceedingly large numbers are known to impede the flight ability and behaviour of the host insects. Among the class Insecta, order Coleoptera is known to harbour a good variety of mite species. An excellent example is the family Scolytidae from which 96 mite species are reported.

The biological control of hemipteran pests like whiteflies employs phytoseiid predators (Gerson and Weintraub, 2012). These mites are also widely employed in the biological control of other greenhouse pests like thrips and aphids. Since they are very efficient in biological control, studies are mainly concentrated on the predatory potential, and related factors which influence their feeding and various plant parameters that can influence the occurrence and abundance of predatory acarines on plants etc. The studies made during the past 30 years have shown that leaf characteristics like domatia and number of trichomes can influence the phytoseiid population (Schmidt, 2014).

Despite the occurrence of a good number of parasitic and predatory mites in association with insects and their ability to impose large impact on the insect host populations, little research has been carried out on this aspect, with an exception of the family Phytoseiidae. Majority of the predatory and parasitic groups of mites associated with insect still remain as unexplored or very poorly explored and in India, much needs to be elucidated regarding the incidence as well as biological relationship of mites with respective insect hosts. A detailed investigation on the natural enemy

complex of insect pests is highly warranted to switch on to biocontrol mode of pest control for rendering an eco-friendly, and feasible method of pest suppression either alone or as a part of an integrated mode of pest management. With this major objective, attention was focussed in the present investigation to undertake detailed studies to elucidate the biocontrol potential of parasitic as well as predatory mite representatives to suppress the populations of respective insect pests. The parasitic mite selected for biocontrol studies was a novel species assigned to the family Podapolipidae of the suborder Prostigmata and order Trombidiformes viz. *Podapolipus palappuramensis* sp.nov. which was recognized as an ectoparasite on the Rice grass hopper, *Oxya hyla*. The predatory mite selected for biocontrol studies was a novel species assigned to the family Blattisociidae and order Mesostigmata viz. *Lasioseius (Lasioseius) moolamkudensis* sp. nov. which was recognized as a very common associate of the highly polyphagous and notorious white fly pest, *Bemisia tabaci*. The parasitic impact of *P. palappuramensis* sp. nov. on the paddy pest *O.hyla* was studied by making comparative assessment of the feeding activity, leaf area consumed as well as the survival and mortality rates of the mite infested (experimental) as well uninfested (control) grass hoppers. The predatory potential of *L. (L.)moolamkudensis* sp. nov. on different life stages of the whitefly was assessed following leaf disc method. The leaf domatial characteristics such as the trichome density and the nature and development of pouch at the junction of leaf veins were studied in 10 different local varieties of chilli plants showing natural infestation with *B. tabaci*, in order to trace their impact in determining the population density and abundance of predatory mites. The chapter also provides data on the comparative studies made on various morphological and biochemical parameters of the white fly infested chilli leaves before and after the release of the predatory mite, *L. (L.) moolamkudensis* sp. nov.

Chapter 7

Review of literature

Insect associated mites still represent a very poorly explored area of research in India and the impact of parasitic/ predatory mites in the biological control of insect pests remains as an uninvestigated field, with the exception of the scattered information available on the biocontrol efficacy of *Hemipteroseius indicus* on the red cotton bug, *Dysdercus koenigii* (Sarangi *et al.*, 2012) and on parasitic mites of mosquito larvae (Rajendran and Prasad, 1988, 1992, 1994). The present part of the thesis, therefore deals with the observations made on the biocontrol potential of representative species of mites showing parasitic as well as predatory modes of association with their respective insect hosts through laboratory culturing as well as field release of the natural enemies (mites) on pests (insect hosts). The biocontrol potential was assessed by making comparative assessment of the feeding damage induced by the respective insects (hosts) on their corresponding host plants before and after release of the parasitic/predatory mite species. In par with the above lines of studies, the review of literature presented here is split up under various heads depending upon the nature of works carried out on the biological control of insect pests using acarine biocontrol agents.

Use of acarine natural enemies in biological control

Biological control of pests by mites refers to all kinds of acarine interactions with pests such as predation, parasitism, parasitoidism, phytophagy, competition, disease transmission and other activities that reduce pest numbers to below economic injury level (Gerson *et al.*, 2003). The use of acarine natural enemies for the biological control of insects has become a fascinating area, gaining attention by the scientific and public sectors. Biological control agents are known to occur in both the superorders of the subclass Acari viz. Parasitiformes and Acariformes.

The first record of a mite being used as a biocontrol agent was that of *HemisarcOPTES malus*, which was found feeding on the oystershell scale, *Lepidosaphes ulmi*, as

revealed through the studies of Shimer (1868 b). The first inundative release with the mass production of mites intended to control the cotton boll weevil was of *Pyemotes* sp. in the cotton fields of Texas as reported by Hunter and Hinds (1904). While conducting studies on the biocontrol efficacy of *H. malus*, Tothill (1918) examined nearly 18,000 scales infesting apple trees in western Canada and reported that at some sites 90–95% of their eggs were killed by the mite. The author stated that *H. malus* exerted excellent control of the pest in western Canada by offering almost complete destruction of scale insect populations on heavily infested trees. Studies made by Uchida and Miyazaki (1935) revealed the potential of the larvae of *Arrenurus* spp. as the natural enemies of the malaria vector mosquitoes like *Anopheles* spp. and they observed that the mosquitoes which were infested with more than four mites appeared inactive and did not attack humans. The association between *HemisarcOPTES* and *Chilocorus* was first recognised by Bartlett and DeBach (1952 b) in California. It was observed that in *HemisarcOPTES*, phoresy enabled to find new host/prey in unexploited areas, and facilitated its dispersal between patches, over short or long distances. The sclerotised integument of the hypopodes served to afford them protection against desiccation and radiation as they become exposed during dispersal. Wade and Rodriguez (1961) reported that clusters of the macrochelid species, *M. muscaedomesticae* attacked and killed the young flies. The ability of *H. malus* to suppress the population of *L. ulmi* was elucidated by Turnbull and Chant (1961) which prompted its successful use in a biocontrol project in Canada. The predatory habit of *Neophyllobius*, a cosmopolitan genus of the family Camerobiidae on the crawlers of California red scale and Oyster-shell fruit scale was revealed through the studies of Meyer (1962) and Richards (1962). Axtell (1963) demonstrated the combined effect of two species of macrochelids viz. *M. muscaedomesticae* and *M. merdarius* and unnamed members of the family Parasitidae on the juveniles of house fly. The emerging fly numbers were found reduced by around 94% thereby revealing the effect of the predators. Mitchell (1968) reported that heavy loads (>30/host) of *Arrenurus mitoensis* on the thorax of the damselfly, *Cercion hieroglyphicum* hindered its movements and might lead to the death of the insect host.

Rao and Sankaran (1969) observed the predatory habit of a eupalopsellid mite, *Saniosulus nudus* on the emerging crawlers of sugarcane scale, *Melanaspis glomerata* in India. Egan and Moss (1969) reported several species of mites parasitic on

cockroaches. Graham (1970) reported that the major factor for the control of storage pests such as almond moth, *Ephestia cautella* and red flour beetle, *Tribolium castaneum* was the members of Blattisociidae. Rodriguez *et al.* (1970) recorded a high rate of housefly control using *Macrocheles* spp. Jalil and Rodriguez (1970) observed that the macrochelid mites bit and fed through the intersegmental membranes of the flies, thereby decreasing their weight. The life span of the mite-free flies was found significantly longer than those with mites. Gauchat (1972) observed the parasitic association of a member of the family Podapolipidae viz. *Podapolipoides grassi* on the Australian plague locust, *Chortoicetes terminifera* and reported that the mite infestation caused a decrease in the vigour of the locust, suggesting the potential of the mites in the biocontrol of the locust pest. Parasitization by the podapolipid mite species, *Coccipolipus epilachnae* was found to reduce the vigor, reproduction and longevity of the Mexican bean beetle upto 33% as revealed through the studies of Smiley (1974) and Schroder (1982). Baker and Eickwort (1975) provided information on another podapolipid species, *Chrysomelobia labidomerae* infesting the milkweed beetle, *Labidomera clivicollis* but the authors could not record any adverse impact of mite infestation on the beetle host.

The adult mites belonging to the family of Hydryphantidae were found to feed on the juveniles of biting flies, mosquitoes, black flies and horse flies as reported by Mullen (1977) thereby indicating their potential in vector control. Reisen and Mullen (1978) reported that in Pakistan, the mite, *A. madaraszi* killed the preovipositing females of several species of mosquitoes belonging to genera such as *Aedes*, *Anopheles* and *Culex* and thereby reduced their population to a great extent. The pattern of parasitisation by *A. crassicaudatus* in midges was explored by Booth and Learner (1978) in South Wales. The authors observed that the females carried more number of mites, and the mite had one principal host, the main period of emergence of which coincided with the mite's life cycle there by suggesting a phenological adaptation. Schroder (1979) suggested the introduction of the podapolipid species, *Coccipolipus epilachnae* parasitic on the Mexican bean beetle, *Epilachna varivestis* into USA to control the adult beetles. The field trials revealed that *C. epilachnae* was restricted to the beetle subfamily Epilachninae.

Studies made by Abro (1982) revealed that parasitism by Arrenurus in damselflies induced decreases in the physical condition of attacked hosts which in turn resulted in

a significant reduction in their flight distance, and thereby increasing the risk of being caught by predators during flight. Observations made by Smith (1983) disclosed that the larval stages of mites belonging to the family Hydryphantidae would feed on the haemolymph of biting flies, mosquitoes, black flies and horse flies. Studies made by Lindquist (1983) proved that tarsonemid mites, especially those belonging to the genus *Iponemus*, which were found to feed on the eggs of pestiferous bark beetles could be specifically called as parasitoids as only a single stage of which fed on the host afterwards it was killed. (Cantwell *et al.*, 1985) came up with the observation that infestation by the mite, *C. epilchnae* could not bring out any reduction in the population of the beetle pests belonging to Epilachninae in laboratory experiments. Fresh water mites belonging to the family Limnesiidae were found to lead a parasitic mode of life on midges and mosquitos as reported by Smith and Oliver (1986). The authors also observed that the larval stages of the mites belonging to the family Hydryphantidae also would feed on the juveniles of midges and mosquitoes.

While conducting an investigation on the potential effects of the ectoparasitic mite, *C.epilachanae* on the host, *E.varivestis* the so called Mexican bean beetle, Conway-Hochmuth *et al.* (1987) observed that the parasitic mite had no significant effect on the feeding, longevity or fecundity of the beetle host. In Australia, Milne and Bishop (1987) made observations on some unidentified species of Bdellidae feeding on Lucerne aphids. The predatory habit of the acarid member, *T.putrescentiae* on the southern corn rootworm and nematodes was reported by Brust and House (1988). The adverse effect of the podapolipid mite, *C. labidomerae* on the longevity and dispersal of the host milkweed beetle, *L. clivicollis* was proved through the laboratory trials made by Drummond *et al.* (1989).

The heterostigmatid mite, *Acarophenax mahunkai* was proved to be an egg parasitoid of the lesser mealworm as revealed through the studies made by Steinkraus and Cross (1993), leading to over 50% reduction of the pest population in the laboratory reared cultures. Laelapidae constitutes an important family of predator used in the control of greenhouse pest and glasshouse pests. Based on the significant feeding impact of laelapid mites like *Hypoaspis miles* on the populations of the greenhouse pest, *Bradysia pauper* and the mushroom pest *Lycoriella solani*, Chambers *et al.* (1993) employed the above species, to control *Bradysia* spp. infesting cyclamen and poinsettia. Gerson (1994) reported the association of the eupalopsellid mite,

Saniosulus nudus with the armoured scales (Diaspididae) in different parts of the world. He further observed that the mite mostly attacked the crawlers. Izraylevich and Gerson (1995) recorded the association of *Hemisarcoptes coccophagus* with the scale insects of the family Diaspididae and the authors reported that the mites attacked the ovipositing females of two species of scales like lantania scale and the oleander scale. Studies made by Hurst *et al.* (1995) revealed the involvement of a podapolipid mite species belonging to the genus *Coccipolipus* in the transmission of Sexually Transmitted Disease (STD) in its host beetle, *Adalia bipunctata* and the infected females showed reduced rate of oviposition and produced less viable eggs.

Ali *et al.* (1997) tested the efficacy of the laelapid species, *H. miles* in controlling the sciarid fly, *Lycoriella solani* which was found to infest cultivated mushroom, *Agaricus bisporus*. The authors observed that crop yield was higher when predators were introduced at spawning period and more mushrooms were produced. James *et al.* (1997) reported the association of the eupalopsellid species, viz. *Eupalopsis jamesi* with the California red scale, *Aonidiella aurantii* and considered this mite as an efficient biocontrol agent of this pest. Martin (1998) carried out ecological and biological studies on the ectoparasitic mite, viz. *Varroa jacobsoni* infesting the honeybee, *Apis mellifera*. Forneck *et al.* (1998) observed an unidentified species of tarsonemid mite feeding on the grape phylloxera and suggested the potential use of tarsonemids in the biological control of some important pests.

Abbot and Dill (2001) noticed that *L. clivicollis* parasitized by the mite, *C. labidomerae* exhibited some altered sexual behaviour, in which the parasitized males displaced the rival males from the females more frequently than the unparasitised males, a behaviour that could be interpreted as the beetle's effort to compensate the loss of fitness by increasing its reproductive potential. The mites were also reported to reduce the survival of nutritionally stressed beetles. Oliveira *et al.* (2003) carried out studies on the biocontrol potential of the prostigmatid mite species belonging to the family Acarophenacidae viz. *Acarophenax lacunatus* which was proved as egg parasite of stored product insects like *Rhyzopertha dominica*, *Tribolium castaneum* and *Oryza ephilussurinamensis*.

Parasitic mites were known to reduce the immunity of the host by suppressing the immunity related genes and this was demonstrated by Yang and Cox-Foster (2005) in

the honeybee, *Apis mellifera* infected with *Varroa*. Mumcuoglu and Braverman (2010) provided a list of the parasitic and phoretic mites associated with dipteran flies in Sinai Peninsula, Egypt and Israel, without mentioning the impact of the relationship. The parasitic mite, *C. labidomerae* of the family Podapolipidae which was found ectoparasitic on milkweed leaf beetle, *L. clivicollis* could feed on the abdominal terga of the beetle and even disperse to another host during mating but even at high population levels, the mite did not affect the fecundity and longevity of the adult beetles as mentioned by Baker and Eickwort (1975). Ectoparasitic species of mites like *M. subbadius* and *M. muscaedomesticae* infesting *D. nigrospiracula* and *D. hydei* respectively were found to significantly reduce the flight endurance by 57% in the former and 78% in the latter, as revealed through the studies of Luong *et al.* (2015). In *Drosophila hydei*, the incidence of the parasitic mite, *M. muscaedomesticae* induced elevated levels of respiration, indicating that parasitism could increase the metabolic cost of the host, as pointed out by Luong *et al.* (2017). A review on the host-parasite relationship between mosquitoes and parasitic mites was made by Atwa *et al.* (2017) and the authors described the role of the larval stages of mites belonging to families like Arrenuridae, Thyasidae, Anystidae, Hydryphantidae as obligate parasites, as they were found to ingest haemolymph by piercing host cuticle.

Studies made by Desurmont *et al.* (2019) on the mite fauna associated with egg masses of the leaf beetle, *Viburnum tinus*, revealed that the constant mite associate, *Tricoribates tri maculatus* had no role in determining the overwintering success of the eggs as well as the survivorship status of leaf beetle. Pohlink *et al.* (2020) assessed the potential of an endoparasitic mite, *Linobia coccinellae* to parasitise the poplar leaf beetle, *Chrysomela populi*, and found that they sustained by feeding on the haemolymph of the beetle but had no significant impact on its longevity or reproductive traits.

Parasitic mites associated with order Orthoptera

There is a long history on the association of parasitic mites with Orthoptera. Howard (1918) reported that the nymphs and adults of Eutrombidium attacked the egg pods of locusts and fed on the eggs. According to Lawrence (1940), members of four families viz. Trombidiidae and Erythraeidae (Trombidiform mites), and Tarsonemidae and Tyroglyphidae (Sarcoptiform mites) were found to include mites which live

permanently or temporarily on locusts and grasshoppers. Studies made from North America by Severin (1944) revealed that a single *Eutrombidium* species sucked out 3 to 30 grasshopper eggs during the entire duration of its life. Rizvi and Aziz (1966) observed that mites belonging to the genus *Eutrombidium* infected the thorax and under the wing and elytron pods of older hoppers and adults. Huggans and Blickenstaff (1966) reported that *Eutrombidium* species would feed exclusively on the eggs of *Saltatoria*. Ectoparasitic larvae of *E. locustorum* were found to get attached to the grasshopper hosts by piercing either their integument or a wing vein, often during moulting, as mentioned by Rees (1973). Anderson and May (1982) mentioned that the larvae of *Eutrombidium* mostly preferred to select members of the family Acrididae as their hosts. According to Welbourn (1983) members of Eutrombidiidae and Erythraeidae can act as potential biocontrol agents of Orthopteran pests. Various species of the genus *Podapolipus* were known to parasitise insect hosts representing three orders like Orthoptera, Blattodea and Coleoptera as mentioned by Husband (1989). Four new species of parasitic *Podapolipoides* were also described by the same author (1995), recorded from different species of Acrididae viz. *P.andrei* from *Oxya humeralis*, *P. fain* from *Gastrimargus africanus*, *P. volkovskyi* from *Cyrta canthacristatarica* and *P.lavoipierrei* from *Morphacris fasciatus*. Morphological descriptions and illustrations of two new species of Podapolipidae viz. *Podapolipoides hopperae* and *Podapolipus nitidulae* were provided by Ramaraju and Mohasundaram (1996) from Tamil Nadu. Both the species were found parasitic on the Acridid, *O. nitidula*. The authors were able to record the larval and adult females of both the species. Two novel species of Erythraeidae viz. *Charletonia keralicus* and *C. sureshi* were collected and described by the same authors (1998) from two species of Acrididae, *Oxya* sp. and *Attractomorpha* sp. respectively. Both the species were found ectoparasitic on the insect hosts collected from Tamil Nadu. Ramaraju and Suresh (1999) described a novel species of Podapolipidae viz. *P.mohanasundarami* parasitic on *Oxya* sp. in Tamil Nadu.

Haitlinger (2002) described two novel species of *Leptus* viz. *L. hospeticus* ectoparasitic on *Oedaleus abruptus* from India and *L. laviniacus* ectoparasitic on *O.nitidula* and *Oxya* sp. from Srilanka. Husband and Zhang (2002) reported a novel parasitic species of Podapolipidae viz. *Wetapolipus jameisoni* on an orthopteran host, *Hemideina maori*. The effects of parasitization by the grass hopper mite, *E.*

locustorum on the survival, reproduction and life history characteristics of two grass hopper species viz. *Melanoplus sanguinipes* and *Ageneotettix deorum* were assessed by Branson (2003). Otterstatter and Whidden (2004) reported that the infestation by *L. buchneri* on bee hosts can affect the bee physiology causing lethargic behavior, reduced life span and also weaken the colony health. Husband *et al.* (2005) recorded two new species of *Orthapolipus* parasitic on three species of American Tettigoniidae. According to Husband *et al.* (2008), 29 ectoparasitic mites were included in the genus *Podapolipus* in which two species parasitized Blattodea, 12 species on coleopterans and 15 species on Acrididae but the parasitic impact of the mite on host were not discussed by the authors. A novel species of *Podapolipoides*, viz. *P. anacridii* was described by Hajiqanbar and Joharchi (2011) parasitic on *Anacridium* sp. from Iran. Sultana *et al.* (2012) assessed the impact of parasitism by *Eutrombidium trigonum* on the life history characteristics of three species of *Hieroglyphus* viz. *H. perpolita*, *H. oryzivorou* and *H. nigrorepletus* Pakistan. The authors reported a lower rate of survival in mite-parasitized specimens and the females showed reduced initial and total reproduction as compared to un-parasitic species. Anderson (2013) found that the parasitic mite *E. locustorum* decreased the survival rate of adult grasshopper, *Melanoplus sanguinipes* and also increased its grazing activity.

The order Orthoptera was found to be usually parasitized by five genera of podapolipids and Lindquist and Sidorchuk (2019) made a review on the members of the genus *Podapolipus* parasitic on 31 species of Orthopteran members. In their study, the authors also reported a novel species belonging to the genus *Podapolipus*, *P. gryllacridi* parasitic on the Australian gryllacridid cricket, *Chauliogryllacris* sp. According to Rahmatzaei *et al.* (2021), the three genera of parasitic mites like *Podapolipoides*, *Orthapolipus*, *Wetapolipus* were reported to be confined to the members of Orthoptera. Majidi *et al.* (2022) reported an ectoparasitic species of podapolipidae viz. *Podapolipoides chorthippus* from an acridid, belonging to the genus *Chorthippus*.

Phytoseiid predators in the biological control of insects with special reference to whiteflies

Mesostigmatid mites of the family Phytoseiidae are the best known and most studied group of predators feeding on mites, small insects, nematodes, plant exudates and

fungi. With a species diversity spanning over 2,400 species worldwide (Demite *et al.*, 2018), phytoseiid mites were used in three levels of biocontrol strategies such as the classical biological control targeted to control invasive pests; augmentative biological control comprising the mass release of natural enemies and conservation biological control, intending to enhance the natural enemy population in agro-ecosystem, through appropriate management tactics (Letourneau *et al.*, 2011; Ratnadass *et al.*, 2012). The early reports on the potential of phytoseiid mites in suppressing population of rust mite and spider mite pests were those of Parrot *et al.* (1906), Ewing (1914) and McGregor and Mc Donough (1917). Later studies by Smith and Goldsmith (1936) proved their potential to control tarsonemid mite populations also. Studies made by MacGill (1939) probably formed the first report on the predatory habit of insect pests like the onion thrips, by the predator *N. cucumeris* (then named *Typhlodromus thripsi* n. sp). Years later, Ramakers and Van Lieburg (1982) mass reared the species on the flour mite, *Acarus siro* for release in glasshouses for controlling thrips population. Different species of *Amblyseius* were described as potential biocontrol agents of thrips in commercial greenhouses as mentioned by Ramakers (1978; Ramakers and Van Lieburg, 1982). Later on, it was found that another species of *Neoseiulus*, *N. cucumeris* displayed more efficient predatory potential on thrips as reported by de Klerk and Ramakers (1986). At several instances, the predation was found successfully defended by thrips as reported by Bakker and Sabelis (1989) in the case of the larvae of *Thrips tabaci*, which often exhibited defensive behaviour by ejecting out a rectal fluid to repel the phytoseiid predators. The efficiency of *N. barkeri* to control thrips was evaluated by Brodsgaard and Hansen (1992). Van Houten *et al.* (1995) observed that the prevalence of short day conditions during winter would drive the predators like *A. cucumeris* and *A. barkeri* to enter in to diapause. In this study, the authors demonstrated the efficiency of five subtropical mites, *A. hibisci*, *A. degenerans*, *A. limonicus*, *A. scutalis* and *A. tularensis* to overcome the diapause problem. The efficiency of predators like *Iphiseius degenerans* and *Typhlodromalus limonicus* was tested on thrips by authors like van Houten (1996) and van Rijn *et al.*, (1999). The importance of using more than one predator, exhibiting intraguild predation, for making effective pest control was discussed by Hatherly *et al.* (2005). Messelink *et al.* (2006) made a comparative study of two phytoseiid species viz. *Typhlodromips swirskii* and *N. cucumeris* which were commonly used for controlling thrips on green house crops. Accordingly, *T. swirskii* was found to establish its

population more successfully than the latter and was proved as the more efficient predator of thrips. The same authors (2008) tested the efficacy of 10 species of phytoseiid predators in controlling the western flower thrips and they ascertained that *T. limonicus*, *T. swirskii* and *E. ovalis* could be efficiently used in the biological control of thrips as well as whiteflies. In a study made by Pijnakker and Ramakers (2008), it was observed that *A. swirskii* and *E. ovalis* were promising control agents of thrips among the other phytoseiid species compared. The predatory potential of phytoseiid species like *A. swirskii* and *N. cucumeris* was evaluated on the chilli thrips, *Scirtothrips dorsalis* and found that the release of phytoseiids could control the thrip population upto 63 days of release (Arthurs *et al.*, 2009). Calvo *et al.* (2015) discussed the rationale behind the wide use of *A. swirskii* in the control of greenhouse pests. The authors put forward several reasons for the success of this predator which included its ability to thrive on a wide array of pests like thrips, whiteflies and mites, its ability to develop on alternative food sources like pollen and nectar and the possibility of rearing it on factitious prey source for the ease of its mass production. The predatory potential of *E. gallicus* on white flies and thrips was evaluated by van Houten *et al.* (2016) and it was observed that the mite could be effective as a biocontrol agent of whiteflies, but not of thrips. Ahmed and Lou (2018) evaluated the potential of the predators, *A. swirskii* and *N. cucumeris* to control population of western flower thrips on cherry tomato and observed that the above predators could effectively suppress the population of thrips. Since the thrip eggs were found embedded in leaf tissue, a general notion existed that the eggs would not be accessible to predators and therefore the latter would feed on the first and second instars of the prey thrips. Despite the above general notion, Nguyen *et al.* (2019) proved that the phytoseiid predators were able to feed on the eggs embedded in the leaf tissue. The reduced rates of predation, oviposition and survival observed in some phytoseiid species often were found to result from the shorter photoperiod, cooler temperature and low vapour pressure. This necessitated the need for the assessment of predatory potential of more number of phytoseiids as pointed out by Labbe *et al.* (2019). The above authors evaluated the potential of the phytoseiid species, *Transeius montdorensis* on the western flower thrips and established that the predator could efficiently control the green house thrips.

The literature available on the predatory mites associated with white flies dates back to 1960s, such as those of Teich (1966) and Elbadry (1967) on different predators like

E. rubini and *A. swirskii* which brought down the population of *B. tabaci*. Different species of *Amblyseius* were reported to predate on various stages of the whitefly. The role of *A. aleyrodis* in controlling the population of cotton whitefly, *B. tabaci* was studied by Elbadry (1968). The members of the genus *Eusieus* were found to be efficient biocontrol agents of white flies and which was proved through the studies made by Wysoki and Cohen (1983) on *E. rubini*, the adults of which were found to occur naturally in association with *Parabemisia myricae*, and feeding on all stages of the latter. The ability of *E. ovalis* to predate and reproduce on a diet of *B. tabaci* under laboratory conditions was revealed through the studies of Borah and Rai (1989). Duly considering the importance of life history traits of predatory mites in the biological control of whiteflies, Nomikou *et al.* (2001) conducted studies on the life history traits of different species of phytoseiid predators like *Typhlodromous athiasae*, *Typhlodromips swirskii*, *N. barkeri*, *E. scutalis* and *Phytoseius finitimus* on a diet comprised of different life stages of white flies.

Laboratory as well as field trials undertaken by Nomikou *et al.* (2002) on the phytoseiid predators, *E. scutalis* and *T. swirskii* revealed that both species could survive on a diet of *B. tabaci* infesting cucumber, thereby proving their ability to control the numbers of *B. tabaci* on greenhouse cucumbers. Blockmans *et al.* (2005) investigated the role of *A. swirskii* in suppressing the populations of two species of whiteflies viz. *Trialeurodes vaporariorum* and *B. tabaci*. The results of their study enabled to draw the conclusion that the use of phytoseiid predators might become a major step in the biocontrol of whiteflies. In India, Chauhan and Takur (2007) reported the occurrence of *E. delhiensis* on rose in association with the greenhouse whitefly, *Trialeurodes vaporariorum*. The efficiency of *A. swirskii* in the control of whiteflies and thrips was evaluated by Messelink *et al.* (2008) under greenhouse conditions. Van Houten *et al.* (2008) tested the potential of the predator, *Typhlodromalus limonicus* in the biological control of *T. vaporariorum*, infesting tomato. Since the study was performed on tomato leaf discs under laboratory conditions, it demanded the greenhouse trials. Messelink *et al.* (2008) observed the efficacy of *E. ovalis* in controlling the whitefly population on greenhouse cucumber crops. Stansly and Castillo (2009) evaluated the potential of three species of predators viz. *A. cucumeris*, *N. californicus* and *A. swirskii* in controlling the whiteflies under field conditions. The study revealed that crops with *A. swirskii* produced more fruits

and the crops with mixed release of *A. Swirskii* and *N. californicus* appeared more persistent.

Xiao *et al.* (2012) came up with an interesting observation on the natural population of predatory mites which could be built up using banker plants. The authors made a demonstration of their study using ornamental pepper, to promote the population build up of *A. swirskii*. As pointed out by Dogramaci *et al.* (2013), the predator *A. swirskii* developed a substantial interest as a biological control agent against mites, thrips, and whiteflies in greenhouse and nursery crops and used to be currently reared and sold commercially in Europe and North America. De Alfaia *et al.* (2018) evaluated the potential of species like *A. largoensis* and *E. concordis* against the giant whitefly, *Aleurodicus cocois* infesting cashew. Results of laboratory trials with different prey egg densities revealed that both the above species of predators could survive at low prey densities. Another species of *Amblyseius*, viz. *A. tamatavensis* was also proved to be an efficient predator of *B. tabaci* as reported by Barbosa *et al.* (2019). Studies carried out by Kozlova *et al.* (2020) revealed that *A. swirskii* and *N. cucumeris* significantly reduced the whitefly population on roses. It was also found that the pest density was affected by predator release rate and also by the time between their introductions.

Predatory habits of the genus *Lasioseius*

The genus *Lasioseius* of the family Blattisociidae could be recognized as diverse genus comprising over 100 described species, showing varied habitats like the soil, litter, fungi and mushroom beds, flowers and leaves of the plants (Chant, 1963). Most of the species assigned to the genus *Lasioseius* were reported to be predatory on invertebrates and many of them were assigned to be nematophagous. Cayrol (1970) reported two types of feeding habits in a species of *Lasioseius*, *L. thermophilus* like mycophagy and nematophagy. Walter and Lindquist (1997) reported that many undetermined species of *Lasioseius* were dominant predators dwelling on tropical rainforest trees and other crops in Australia. *L. scapulatus* was known to feed on nematodes belonging to eight genera, thereby making drastic reduction in their population, as revealed through the invitro studies carried out by Imbriani and Mankau (1983). Tseng (1984) observed that *L. parberlesei* could bring down the populations of major acarine pest of rice such as *Steneotarsonemus spinki* and *Tarsonemus*

fuzhouensis. Walter and Lindquist (1989) discussed the omnivorous habit of the members of *Lasioseius* and the importance of their cheliceral features supporting omnivory among species of the genus. Lesna *et al.* (1995) reported *L. bispinosus* as an effective natural enemy of the bulb mite, *Rhizoglyphus robini*. Studies made by Sheeja and Ramani (2009) disclosed the predatory habit of *Lasioseius* sp. on different life stages of the Red Palm Mite, *Raoeilla indica* such as the egg, larva, nymphal stages and adults. The authors reported that the consumption rate of male predator was comparatively lower than that of the female predator. The consumption rate of *Lasioseius* sp. was high on the egg stage of the prey whereas the adults were least preferred by the predator. Britto *et al.* (2012) observed the predatory habit of *L. floridensis* on *Polyphagotarsonemus latus* under natural conditions, though soil nematodes were recognized to be the most preferred diet for the predator. Angular-Marcelino *et al.* (2014) recorded the incidence of predation by *L. penicilliger* on the infective stages of three species of nematode species viz. *Haemonchus contortus*, *Panagrellus redivivus* and *Rhabditis* sp. Garcia Ortiz *et al.* (2015) evaluated the predatory behavior of the above predator on three species of nematodes such as *Teladorsagia circumcincta*, *Meloidogyne* sp. and *Caenorhabditis elegans* and found that *L. penicilliger* could be used as an effective biocontrol agent against plant parasitic nematodes.

El- Swbaay (2017) observed the feeding habits of *L. aegypticus* on two species of astigmatid mite pests viz. *Rhizoglyphus echinopus* and *Acarus siro* and on the fungus, *Aspergillus niger*. The feeding preference of *L. athiasae* towards different prey species like *T. putrescentiae*, *R. robini*, *Tetranychus urticae* and *M. incognita* was tested by Tawfik *et al.* (2017) and the authors recorded highest reproductive rate on *T. putrescentiae* and *R. robini*. Zhang *et al.* (2020) studied the development of *L. japonicus* on the eggs of *Drosophila melanogaster* and *Sitotraga cerealella*. They found that *L. japonicus* displayed a high reproductive rate and low generation time on the latter. The same authors later (2022) tested the feeding and generation time of *L. japonicus* on *T. putrescentiae* at different temperatures and observed that the increasing temperature shortened the average generation time of the predator.

Leaf characteristics influencing the predatory mite population on plants

Researches over the past few years clearly revealed that the population density of the predatory mites could be largely influenced by the leaf characteristics. It was Lundstrom (1887) who suggested that the structures found under the leaf vein axils called the domatia would act as shelter for predatory mites. Various definitions were given for the term 'domatia' and as per the formal definition given by O' Dowd and Willson (1989) these were represented by the pits, pouches, pockets and tufts of trichomes developed at the junction of leaf veins. Majority of the arthropods which colonized the domatia were found to be of either predatory or fungivorous nature as pointed out by Pemberton and Turner (1989). The dense tufts of trichomes present on the leaves of host plants were found preferred by several species of predatory mites as noticed by Downing and Moillet (1967). Some of the glandular trichomes were found to induce a toxic effect on predators as pointed out by Levin (1973). The leaf preference shown by predators was attributable to several factors like the high humidity offered by the dense trichomes would become suitable for the egg incubation as well as protection from other predators, as mentioned by Sabelis (1981). Overmeer and Van Zon (1984) reported that many species of predatory mites showed preference to leaves with high density of trichomes.

The predatory efficacy was often found enhanced with the increased trichome density as observed by Grevstad and Klepetka (1992) in the case of coccinellid predator on the cabbage aphid. Grostal and O' Dowd (1994) reported that cassava plants often formed pseudodomatia whereby the apex of the plant formed a safe haven for predatory mites. Walter (1996) mentioned that the acarodomatia were small structures, typically having a size of one or two millimeter in diameter. Some plant structures might provide the predators with alternative food as observed by Bakker and Klein (1992) or might provide shelter for the natural enemies as reported by Walter (1996). The preference shown towards the trichome density by the predatory mites was also found dependent on their size and Barret (1994) observed that the smaller species preferred leaf surfaces with higher trichome density in contrast to the larger species which showed decreasing performance as the trichome density increased. It was observed by Van Lenteren *et al.* (1995) that the rate of parasitoidism in *E. formosa* was highest on cucumber variety with intermediate trichomes. Krips

(1999) found that the rate of predation by *Phytoseiulus persimilis* decreased with an increase in the trichome density.

Kennedy (2003) reported that glandular trichomes might produce sticky toxic compounds that would serve to kill the predators. Domatia sometimes would serve as refuge for the predatory mites, which could be achieved by reducing the wettability of leaf tissues and thereby helping to avoid the effect of pesticides on non target mites, as mentioned by Xu *et al.* (2010). Schmidt (2014) therefore emphasised on plant breeding programmes concentrated in developing plant varieties with desirable leaf characters that could enhance natural enemy complex.

Biochemical parameters

In par with the research work carried out during the study on the evaluation of the changes induced in biochemical parameters of the host plant (chilli) owing to infestation by the white fly (*B. tabaci*), in the present review of literature, attention was focussed to include earlier research works done along the above line. White fly infestation on tomato plants was found to induce severe stunting and retardation of plant growth, misshapen, inwardly cupped and remarkably smaller leaves as observed by Cohen and Antignus (1994). Infestation by whiteflies could induce several damages to the host plant such as chlorosis, yellowing and defoliation as recorded by Jetter *et al.* (1997) which in turn would result in lowered photosynthetic pigment contents. Plant oxidative compounds like the phenolics were known to play an important role in imparting chemical defence against herbivory, as pointed out by Appel (1993). Mc Auslene (2004) reported a reduction in various parameters like the plant height, internode length and petiole length due to infestation by the silver leaf whitefly. A decrease in the protein content was reported in the whitefly infested cassava as revealed through the studies of Antony and Palanisami (2006), even though some pathogenesis related proteins were found elevated. Marmit *et al.* (2008) documented that an attack by herbivores would cause considerable change in the metabolism of total phenols and o-dihydroxy phenols. Islam and Shunxiang (2009) observed significant variations in several leaf parameters such as the leaf area and moisture content, chlorophyll content and rate of photosynthesis. Some volatile compounds and enzymes produced due to the feeding activity of herbivores could help in the defense mechanism and in the case of sucking pests, production of several

defensive enzymes like the peroxidases, superoxide dismutase, polyphenoloxidase, catalase and ascorbate peroxidase was reported by Usha Rani and Jyothsna (2010). The authors mentioned that secondary metabolites like phenols, condensed tannins and hydrogen peroxide also could act as defensive enzymes. Yang *et al.* (2011) noticed that whitefly infestation resulted in stunted growth and reduced leaf area in pepper plants. Taggar *et al.* (2014) found that the whitefly infestation on *Vigna mungo* caused remarkable changes in the biochemical characteristics like the total phenol and tannin contents. Kurra and Usha Rani (2015) observed that the feeding activity of *Trialeurodes ricini* on *Ricinus communis* decreased the total carbohydrate and soluble amino acid contents but elevated the level of phenol and other secondary metabolites. Mahadeva (2016) recorded drastic variations in biochemical parameters like total soluble proteins, free amino acids, reducing and non reducing sugars, phenol and photosynthetic pigments in the leaves of host plants owing to infestation by the spiralling whitefly, *Aleurodicus disperses*. The infestation by *B. tabaci* caused a decrease in the photosynthetic rate, resulted due to the secretion of honeydew as observed by Sani *et al.* (2020). Arun *et al.* (2021) evaluated the changes in biochemical parameters of coconut leaves infested with spiralling whitefly. A reduction in the photosynthetic efficiency as well as nutrients like protein, sugar and amino acids was recorded by the authors in the whitefly infested coconut leaves. De-Lima Toledo *et al.* (2021) observed that whitefly infestation in tomato caused substantial changes in the physiological and biochemical parameters of the plant. The infestation significantly increased the phenol content of leaves while reduced the chlorophyll content and carboxylation efficiency. Rizvan *et al.* (2021) evaluated the extent of damage induced by sucking pests including whiteflies on different varieties of cotton, by estimating the leaf area and biochemical constituents like free amino acids, total soluble proteins, total soluble sugars, total flavonoids and phenolics. Being phloem feeders, whitefly infestation could lead to decrease in carbohydrate and protein contents in host plants. While feeding, the nymphs of whiteflies inject enzymes that could alter the crop physiology as stated by Abubakar *et al.* (2022).

Chapter 8

Materials and methods

During the present study, attempts were made to explore the potential of two species of acarine associates in suppressing the populations of respective insect hosts. Of the varied kinds of associations identified during the study, the impacts of two types of interactions such as parasitism as well as predation were elucidated during the study on their respective insect hosts. The parasitic impact of a new ectoparasitic species of podapolipid mite, viz. *Podapolipus palappuramensis* sp. nov. infesting the notorious orthopteran paddy pest viz. *Oxya hyla* and another novel species of predatory mesostigmatid mite belonging to the family Blattisociidae viz. *Lasioseius (Lasioseius) moolamkudensis* sp. nov., predating on the various life stages of the notorious hemipteran polyphagous pest, *B. tabaci*, the so called tobacco whitefly infesting the chilli leaves were selected for conducting detailed studies on their biocontrol potential for suppressing the populations of respective hosts.

A. Assessment of the parasitic impact of *Podapolipus palappuramensis* sp. nov. on the paddy pest, *Oxya hyla*.

I. Selection of parasitic mite for the study.

The parasitic mite, *P. palappuramensis* sp. nov. was selected for the present study, duly considering its abundance and severity of infestation on its host insect viz. the Rice Grass hopper, *O. hyla*. Microscopic examination of field collected specimens of the paddy pest, *O. hyla* revealed the infestation of the mite, *P. palappuramensis* under the hindwings of the insect host, especially on its thoracic and abdominal areas. During heavy infestation, the mites were found moving around all visible body parts of the host insect including the under surface of the hindwings. The eggs of the mite were found deposited exclusively on the hindwings, and its larval females and males were found to occupy the abdomen. The adult females of the mite were found clinging to the abdomen of the grass hopper pest, *O. hyla*.

II. Experimental design

1. Cultivation of the experimental plant (Paddy)

The paddy plant, being the host plant of the present insect host of *P. palappuramensis* sp. nov. was selected as the experimental plant for the current study. For raising the paddy seedlings, seeds of the paddy variety “Jaya” purchased from a farmer were sown in grow bags prepared with loamy textured soils. Watering was done twice a day and after a period of two weeks, the seedlings were transplanted into new growbags. The seedlings were planted in three groups in a single grow bag, each group containing 4-5 seedlings. The seedlings in the growbags were safeguarded from pest attack by girdling with mosquito net completely (Fig. 2.1). The grow bags containing the paddy seedlings were kept in four isolated patches; Set 1: Meant for the release of infested adult insect host, *O. hyla* collected directly from the field, Set 2: Meant for the release of uninfested nymphal stage of the insect host so as to recover adults free of mite infestation, Set 3: Meant for the release of adult insect host which were experimentally infested with the parasitic mite in the laboratory and Set 4: Meant for the release of healthy, mite free adult of the insect host, which could be treated as the control set. The grass hopper pest (*O. hyla*) was released on to the paddy seedlings when the latter attained the growth stage of 2-3 months.

2. Collection of the insect host (*Oxya hyla*) and the parasitic mite (*Podapolipus palappuramensis*)

Collection of the rice grass hopper, *O. hyla* was made using a sweep net from a paddy field at the Kavanad region of Thrissur Dt. (10°22'02.4"N 76°19'46.3"E). The grass hoppers were collected from the paddy fields through sweeping, with the help of sweep nets and were put in plastic bottles of 30x8 cm size, along with the paddy leaves so as to keep the collected specimens alive during transportation to the laboratory for further studies. In the laboratory, the grass hopper specimens were carefully examined under a stereozoom microscope (Labovision KS z0850) to locate the incidence of natural infection by the parasitic mite, *P. palappuramensis* sp. nov. on different parts of their body. The field collected grass hopper specimens were not refrigerated in order to maintain the vigor of both the host as well as the parasitic mite. Locust specimens exhibiting natural infestation by the parasitic mite, *P. palappuramensis* sp. nov. alone were considered for the purpose of artificial release on to experimental sets

of paddy seedlings grown and maintained under netted condition. Simultaneously, the mite specimens were preserved, dehydrated, cleared and slide mounted in Hoyer's medium for subsequent taxonomic studies, following the procedures described in detail in part-I.

2. Rearing of the grass hopper host, *Oxya hyla* for release onto experimental plants

The nymphal stages of the rice grass hopper, *O. hyla* were collected from the paddy field at Kavanad region of Thrissur Dt. by active sweeping with the help of sweep nets, and were examined under a stereozoom microscope to verify their infection status with respect to the parasitic mite, *P. palappuramensis* sp.nov. under natural conditions. Mite free nymphal stages collected from the field were then released onto the paddy seedlings maintained in isolation and rearing was carried out until they attained the adulthood (Fig. 2.2 A, C). The adult grass hoppers collected from this captive condition were used for further experiments.

3. Setting up of experimental and control plants to facilitate studies on mite-host relationship through experimental infestation

The adults of the grass hopper host, *O. hyla* reared under captive condition were considered for experimental infestation with the parasitic mite, *P. palappuramensis* sp. nov. For this, 30 nos. of larval females and 10 nos. of males of the parasitic mite were isolated from the mite infested grass hoppers using a fine camel hairbrush and were subsequently released on to the undersurface of the hindwings of the live adult specimens of *O. hyla* reared under captive condition. The mite infested adult grasshoppers were then released on to the paddy seedlings which were kept isolated and maintained in netted condition. A total of 20 such adult individuals of *O. hyla* were released on to the paddy seedlings and this was treated as the experimental set. A similar set of paddy seedlings with the same number of mite free adults of *O. hyla*, was considered as the control set in order to make a comparative study on the impact of parasitic mite infestation.

4. Assessment of feeding damage induced by *Oxya hyla* on the leaves of the host plant (paddy)

The feeding impact of the rice grass hopper, *O. hyla* on paddy seedlings was assessed by measuring the leaf area fed by the adult stages of the grass hopper on paddy leaves in the experimental and control set ups, on alternate days (Fig. 2.2, B). For measuring the area leaf consumed by the grass hopper, the laminar portion containing the fed area was cut with the help of a scissors from both the experimental and control sets of paddy plants and the fed areas were marked on a graph paper to calculate the surface area fed by the insect. Continuous observations were made and the fed area were measured on every alternate days till the death of the grass hopper in the experimental set up. The leaf area consumed by all the 20 adult grass hoppers were measured and the data were recorded for a period of 29 days, since all the grasshoppers in the experimental set up died on the 29th day. The seedlings were renewed in the growbags whenever it was found necessary. Statistical significance of the data recorded on the variations in the leaf area consumed by the mite infested (experimental set up) and mite free (control set up) grass hoppers was tested following Wilcoxon Signed Rank Test and presented .

5. Assessment of mortality rate of the grass hopper, *O. hyla* in the experimental and control set up

Data on the mortality rate, i.e. the number of specimens of the grass hopper, *O. hyla* that died in the control and experimental sets were recorded on alternate days until the death of all the individuals.

B. Studies on biocontrol potential of predatory mites on the notorious white fly pest (*Bemisia tabaci*) infesting chilli plants

Duly considering the heavy infestation of the white fly pest, *B. tabaci* on chilli plants in many sampling localities, in the present study attempts were made to locate the predatory mite populations seen in association with the above pest on chilli plants, in order to explore the biocontrol potential of the most common and abundant species of predatory mite. Identification of the most common, abundant and suitable acarine candidate with exceedingly high predatory potential on *B. tabaci* was made by

undertaking detailed studies on the population density and abundance of predatory mites distributed on the foliage of different varieties of chilli plants.

Assessment of population density and abundance of predatory mites on different varieties of chilli plants

Data on the population density of predatory mites distributed on the leaves of different varieties of chilli plants showing natural infestation with the white fly pest, *B.tabaci* were recorded by counting the number of predatory mites present on individual leaves. For this, 3 leaves each were collected from the upper, middle and lower tiers of 10 local varieties (Var. LV1-LV10) of chilli plants (Fig. 2.3, 2.4) from localities viz. Moolamkudam (10°23'19.8"N 76°19'33.4"E) and Manissery (10°46'43.1"N 76°20'26.2"E) in Thrissur and Palakkad districts respectively. The leaves thus collected were put in separate polythene bags and brought to the laboratory for further studies. The chilli leaves were carefully examined under a stereomicroscope in the laboratory in order to identify the common species of predatory mites associated with the white fly population. The number of predatory mites on individual leaf was counted and recorded.

C. Studies on the relationship between the number of trichomes on chilli leaves and abundance of predatory mites on different varieties of chilli plants

As the trichomes in chilli leaves were mainly found distributed at the junction of leaf veins (axils of major leaf veins), in the present study, the number of trichomes present at the leaf axils were considered for counting. The number of trichomes present at 1.0 sq. cm area of chilli leaves was counted by demarcating 1.0 sq.cm. area, using a window prepared of a thick sheet of paper (Fig.2.5). Using this window method, the number of trichomes present at 1.0 sq.cm area on the laminar surface was counted on individual leaf samples collected from the different local varieties of chilli plants. Data recorded on the number of trichomes present at the 1.0 sq.cm area of all the leaves were considered for the assessment of population density of the predatory mites. Apart from this, attempts were also made to locate the presence and structure of pouches (Fig. 2.5 B) developed at the axils of major veins on the abaxial surface of chilli leaves collected from the different varieties of chilli plants.

D. Assessment of predatory potential of *Lasioseius (Lasioseius) moolamkudensis* sp. nov. on different life stages of *Bemisia tabaci* under laboratory conditions

I. Selection of the predatory mite, *Lasioseius (Lasioseius) moolamkudensis* sp. nov.

Being the most abundant species of predatory mite found distributed on chilli plants naturally infested with the white fly pest, *B. tabaci*, *L. (L.) moolamkudensis* sp. nov. was selected for making detailed studies on its biocontrol efficacy. The species was found associated with different life stages of the whitefly and hence cultures of the predatory mite were maintained on chilli leaf discs infested with *B. tabaci*. The leaf discs were prepared and maintained on moisture saturated cotton pads in petri dishes in the laboratory (Fig. 2.6 B, C).

II. Selection of host plant for raising of pest population

Chilli plant was selected during the present study to raise the cultures of the pest viz. the tobacco white fly *B. tabaci*, giving due weight to the abundance of predatory mites on chilli, even though *B. tabaci* was reported to be a highly polyphagous species on various crops. The local variety of chilli selected for the culturing the pest population was *Capsicum annuum*, based on the abundance of predatory mites on its foliage.

III. Experimental design

1. Cultivation of host plants and experimental release of whitefly and predatory mite

Chilli plants required for the study were cultivated by sowing the seeds collected from ripened fruits in grow bags. The seedlings of chilli plants were transplanted into 4 growbags and the grow bags were maintained securely under netted condition (Fig. 2.6 A, D, E) to make them free from pest attack under natural conditions. The adults of the white fly pest, viz. *B. tabaci* collected from the field were released on to the leaves of four potted chilli plants mentioned above, when they attained the growth stage of two months. After 2-3 weeks of whitefly infestation, the predatory mites collected from the field were released onto two of the white fly infested plants which ensured supply of predatory mites for the experiment. The remaining two chilli plants

were maintained free of predatory mites to facilitate the supply of whitefly stages for carrying out the experiment.

2. Assessment of biocontrol potential of the predatory mite, *Lasioseius (Lasioseius) moolamkudensis* sp. nov. on *Bemisia tabaci*

a. Experimental arena

Assessment of biocontrol efficacy of the predatory mite, *L. (L.) moolamkudensis* sp. nov. was carried out on experimental arena comprised of leaf discs of chilli plants. The experiments were initiated by collecting the white fly infested chilli leaves. The collected leaves were screened under a stereozoom microscope (Labovision KS z0850) to locate the different stages of *B. tabaci*. The leaves were then thoroughly cleaned with cotton except the white fly infested areas. The experimental arenas were prepared by cutting chilli leaf discs (3x3 cm) from the white fly infested areas of the chilli leaves. The leaf discs were examined under a stereozoom microscope to locate the different life stages of *B. tabaci*. Care was taken to ensure that the desirable numbers of a particular life stage of the whitefly (egg/ nymph 1/ nymph 2/ nymph 3/ nymph 4) alone were left on the abaxial surface of chilli leaves. The leaf discs (3x3 cm) were kept upside down on a water saturated cotton pad placed in a petridish and were carefully spread out, with the edges lined with a wet tissue paper, instead of wet cotton wick which entangled the legs of the predatory mites. Different life stages of *B. tabaci* such as the egg, and the nymphs 1-4 were maintained in different densities like 5, 10, 15 and 20 on the experimental arena. Likewise, seven replicates were prepared for the experimental set up to assess the predatory potential.

b. Release of the predatory mite, *Lasioseius (Lasioseius) moolamkudensis* sp.nov.

For the release of the predatory mite onto the experimental arena prepared as described above, the adult females of *L. (L.) moolamkudensis* sp. nov. were collected from the white fly infested chilli plants. Prior to their release on to the experimental arena, the females of the predatory mite were starved for six hours by keeping them on leaf discs free of any whitefly infestation. Then the starved female predatory mite was released singly onto the leaf disc. The experimental set up was kept undisturbed for 24 hours. Observations were made seven times per day in order to record data on the predatory activity, rate of predation etc. of *L. (L.) moolamkudensis* sp. nov. on the

different life stages of the white fly, *B. tabaci* in the laboratory. The results were subjected to statistical analysis using IBM-SPSS software. In order to verify whether there was any significant variation in the rate of consumption of the predator on the different stages of the whitefly at different prey densities, Kruskal-Wallis test was performed.

E. Evaluation of biocontrol potential of *Lasioseius (Lasioseius) moolamkudensis* sp. nov. in the suppression of the whitefly population on potted plants

1. Cultivation of chilli plants

The chilli seedlings were planted in six different grow bags, in the order that two seedlings were planted per grow bag. When the chilli seedlings in the grow bags attained the six leaf stage, they were kept in a protected area girdled by mosquito nets to prevent attack of insect/mite pests. In the netted area, the grow bags were arranged in three groups and numbered as T1, T2, T3.

Set T1: For release of whitefly and subsequent release of predatory mite.

Set T2: For release of whitefly.

Set T3: Healthy uninfested chilly plants.

2. Experimental release of white fly and its predator, *Lasioseius (Lasioseius) moolamkudensis* sp. nov. on to chilli seedlings

Experimental release of the white fly, *B. tabaci* and its predator, *L. (L.) moolamkudensis* sp. nov. on to the potted chilli seedlings was done following two steps. The white fly, *B. tabaci* was released onto chilli seedlings when the latter attained the growth stage of 2 months. 20-30 adults of *B. tabaci* were transferred on to the chilli seedlings grown in the grow bags of set T1 and T2 while the set T3 was kept as the control, free of infestation. A time lapse of one month was allowed for the buildup of white fly population, after which various parameters like the population density of the whitefly, phytochemical and morphological aspects of the chilly plants grown in the grow bags T1, T2 and T3 were analysed in the laboratory. One month after the introduction of the whitefly, the predatory mites were released on to the chilli plants of set T1. For this, 40 adult females and 10 adult males of *L. (L.) moolamkudensis* sp. nov. were released with the help of a fine brush on to the chilli

plants in the T1 grow bag. After an interval of 35 days, the various biochemical parameters of the experimental chilli plants were studied to collect data on the impact of the predatory mite on the white fly infested plants.

3. Estimation of population density of the whitefly, *B. tabaci*

The population density of different life stages of the whitefly, *B. tabaci* on the leaves of chilli plants was recorded at weakly intervals. The number of white fly life stages present on three leaves representing the upper, middle and lower tiers of each chilli seedling in each grow bag T1, T2 and T3 was counted, using a hand lens. Data recorded on the number of life stages were used for the estimation of population density of white flies on the chilli seedlings.

4. Analysis of the morphological/biochemical parameters of the test plants

a) Measurement of leaf area

Attempts were made during the study to record the variations in the leaf area of the control and experimental chilli plants in order to gather information on the impact of the predatory mite in reducing the leaf damage by suppressing the pest population. Leaf area on the control and experimental chilli plants was measured by plucking the leaves randomly from different positions of the plants, for each group. The leaf area was measured and calculated using a graph paper.

b) Analysis of moisture content

The moisture content of the leaves of both the control and experimental chilli plants was estimated by collecting the fresh leaves and taking the weight of which using a weighing balance. The leaves were then shade dried for 2 weeks and their weight was taken again. The percentage of moisture content of each sample was estimated following the equation:

$$\% \text{ of moisture content} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Fresh weight}} \times 100$$

The moisture content of 6 leaf samples from each set were analysed based on the above equation.

c) Estimation of photosynthetic pigments

The concentration of photosynthetic pigments like chlorophyll a, chlorophyll b, total chlorophyll and total carotenoids present in the white fly infested (experimental) and uninfested (control) chilli leaves was estimated following the method of Arnon (1949), as per the procedure given below:

200 mg of fresh chilli leaves were weighed and homogenized in 20 ml of 80% ice cold acetone using a mortar. It was then centrifuged at 5000 rpm for 10 minutes at 4°C. The above procedure of centrifugation was repeated until the residue became colourless. The supernatant was collected in a volumetric flask and it was made upto 100 ml with 80% acetone. The absorbance of the solution was measured at wave lengths of 470, 646, 663 and 750 nm respectively using a microplate reader. The concentration of both the total chlorophyll (Chla+b) and carotenoid contents was calculated and expressed in mg chlorophyll/ carotenoids g⁻¹ dry weight of the leaf sample.

$$\text{Total chlorophyll (a+b)} = \frac{20.12 (A_{646} - A_{750}) + 8.02 (A_{663} - A_{750})}{\text{Fresh weight of the sample}} \times \text{Volume}$$

$$\text{Carotenoid} = \frac{1000 (A_{470}) + 3.27 (\text{Chl a} - \text{Chl b})}{\text{Fresh weight of the sample} \times 229} \times \text{Volume}$$

Where,

$$\text{Chlorophyll a } \mu\text{g/g} = \frac{12.69 (A_{663} - A_{750}) - 2.69 (A_{646} - A_{750})}{\text{Fresh weight of the sample}} \times \text{Volume}$$

$$\text{Chlorophyll b } \mu\text{g/g} = \frac{22.9 (A_{646} - A_{750}) - 4.68 (A_{663} - A_{750})}{\text{Fresh weight of the sample}} \times \text{Volume}$$

d) Estimation of total phenol

The total phenolic concentration in the chilli leaves was estimated following the method of Bray and Thrope (1954). For this 0.5 gram of leaf tissue was weighed and homogenized with 5 ml of 80% alcohol using a mortar. This was then centrifuged at 10,000 rpm for 20 min. at 4°C. A known aliquot (0.1 ml) of supernatant was pipetted out and made upto 5 ml using distilled water in a test tube. 0.5 ml of Folin-Ciocalteus

reagent (1:1) and 2 ml of 20% sodium carbonate were added to the test tube. This mixture was then heated for 1 minute in a water bath. Tannic acid was used as the standard. The absorbance of the solution was measured at 650 nm. Phenolic concentration was calculated as per the following formula:

$$\text{Concentration of sample} = \frac{\text{Concentration of Standard} \times \text{OD of Sample}}{\text{OD of Standard} \times 5/0.5\text{g} \times 0.1}$$

e) Estimation of protein (Lowry's method)

The total protein content of chilli leaves was estimated based on Lowry's method. For this, 500 mg of leaf was weighed and homogenized in 5 ml of phosphate buffer (pH 7). This was then centrifuged at 10000 rpm for 20 min. 0.2 ml of the sample was pipetted out from the supernatant and made upto 1.0 ml with distilled water in a test tube. To this, 5 ml of reagent C was added and allowed to stand for 10 minutes. 0.5 ml of reagent D (Folin-Ciocalteus reagent) was added to this test tube and was incubated in dark for 30 minutes. The development of blue colour was observed after 30 minutes. BSA was used as the standard. The absorbance of the solution was measured at 660nm. A standard graph was drawn and the amount of protein in the sample was calculated based on the following formula:

$$\text{Concentration of the sample} = \frac{\text{Concentration of standard} \times \text{OD of sample}}{\text{OD of Standard} \times 0.5\text{ g}}$$

a. Preparation of reagent A

The reagent A was prepared by mixing 2 g of sodium hydroxide and 10 g of sodium carbonate in 500 ml distilled water.

b. Preparation of reagent B

The reagent B was prepared by mixing 0.5 g of copper sulphate and 1.0 g of potassium- sodium tartarate in 100 ml distilled water.

c. Preparation of reagent C

The reagent C was prepared by the proper mixing of 50 ml of reagent A and 1.0 ml of reagent B.

Chapter 9

Observation

This part of the thesis deals with the results of studies carried out on the biocontrol potential of two species of mites, exhibiting parasitic as well as predatory types of association with their respective insect hosts. As discussed in the first part of the thesis, a total of 65 species of mites could be collected from 24 species of insect hosts, of which seven species were found to display an ectoparasitic mode of life style on their respective hosts. The ectoparasitic species of mites recovered during the study were *Canestriniella batocera* sp. nov. and *Neosilphitrombium gratum* from *Batocera rufomaculata*, *Athogavia oryctae* sp. nov. and *Tyrophagus putrescentiae* from *Oryctes rhinoceros*, *Leptus treati* and *Locustacarus chinensis* sp. nov. from *Oxya chinensis*, *Leptus treati* and *P. palappuramensis* sp. nov. from *Oxya hyla*. Nine species of mites were found to enjoy a predatory habit on insect species such as the white flies by sharing a common arboreal habit on the foliage of respective host plants of their prey species. The predatory mites recorded during the study included *Amblyseius largoensis* associated with both *Bemisia tabaci* and *Aleurothrixus floccosus*, *A. channabasavannai*, *A. vasiformis*, *Euseius finlandicus*, *E. ovalis*, *Transeius kroeffis*, *L. (L.) moolamkudensis* sp. nov., *Cunaxa anomala* and *C. heterostriata*. Of the seven species of ectoparasitic mites collected, a novel species of podapolipid mite viz. *P. palappuramensis* sp. nov. was selected for conducting detailed studies on the biocontrol potential by elucidating the parasitic impact of the mite on its insect host, *O. hyla*, the popularly called rice grass hopper. Among the nine species of predatory mites collected, one novel species of mesostigmatid predator belonging to the family Blattisociidae viz. *L. (L.) moolamkudensis* sp. nov. was considered for detailed exploration of its predatory potential on the different life stages of a notorious pest called the tobacco white fly, *B. tabaci*. Data were collected on the predatory potential of *L. (L.) moolamkudensis* sp. nov. to suppress the population density of *B. tabaci* on potted plants .

A. Assessment of the parasitic impact of *Podapolipus palappuramensis* sp. nov. on the paddy pest, *Oxya hyla*.

I. Feeding damage induced by *Oxya hyla* on the leaves of the host plant (paddy)

A comparative assessment was made on the leaf damage induced by the grass hopper, *O. hyla* in the experimental (mite infested) and control (mite free) set ups and the data made on the above were presented in Table-2.1 & Fig. 2.7. The assessment was made by measuring the laminar area consumed by the individuals of *O. hyla* in the experimental (mite infested) and control (mite free) set ups for a period of 29 days and comparing the differences between the two. It was observed that infestation by the ectoparasitic mite, *P. palappuramensis* sp. nov. induced significant reduction in the feeding activity of its host grass hopper, *O. hyla* when compared to that of the control (mite free) grass hoppers. This was clearly reflected on measurement of the area of consumption by the grass hoppers. The mean area of consumption on paddy leaves by the grasshoppers kept in the control and the experimental set ups when measured for a period of 29 days revealed that in the experimental set up the average leaf area consumed by infested grasshoppers increased slightly for 4-10 days and then decreased after the 12th day (Table 2.1, Fig. 2.7). This decreasing trend of foliar consumption continued in the experimental set up until the 28th day and on the 29th day, the entire mite infested grass hoppers were found dead. A percentage increase of 4.08, 10.72, 24.20 and 12.87 could be recorded respectively from fourth day to the tenth day. Afterwards, on the 12th day, a 4% decrease in leaf area was observed. On the 28th day, the % decrease in the leaf area consumed by the infested grasshoppers was 99.43 compared to the uninfested grasshoppers. On the other hand, in the control set up, the feeding activity of the uninfested (mite free) grass hoppers was found almost static and hence the average leaf area consumed also remained more or less similar. As presented in table-2.1, the mean foliar area consumed by the mite infested grasshoppers (in the experimental set up) for a period of 28 days was 75.60 cm² and that of the control set up (mite free grasshoppers) was 114.27 cm², thereby enabling to recording 33.84% reduction in the foliar consumption owing to mite infestation. The data recorded for the mean area of consumption by the grass hoppers in the experimental and control set ups on paddy leaves when subjected to statistical analysis

following Wilcoxon Signed Rank Test revealed significant difference ($p < 0.05$) in the leaf area fed by the mite infested and mite free rice grasshoppers.

II. Survival and mortality rates of the rice grass hopper, *O. hyla* in the experimental and control set up

The podapolipid mite, *P. palappuramensis* sp. nov. was found to exert a profound impact on the survival and longevity of the rice grass hpper, *O. hyla* when compared to the healthy, mite free individuals. As presented in table 2.1, the mite infested grasshoppers (experimental set up) were found to attain early mortality and undergone death on the 18th day while the mite free grass hoppers survived upto the 29th day (Fig. 2.8). In the control set up (mite free grasshoppers), mortality was found initiated on the 26th day and the last grasshopper succeeded to survive upto the 36th day. As the mite infestation progressed, it was found that grasshoppers exhibited lethargic behaviour and loss in vigour. The infested grasshoppers were found to hide sluggishly among the leaves and were seldom seen on the exposed leaves of paddy plants unlike the active feeders in the control group.

B. Studies on biocontrol potential of predatory mites on the notorious white fly pest (*Bemisia tabaci*) infesting chilli plants

I. Population density and abundance of predatory mites in relation to leaf domatia characteristics in different varieties of chilli plants

The average number of predatory mites showed variation depending upon the varietal difference of the chilli plants examined. The characteristics of leaf domatia such as the number of trichomes and the size and appearance of the pouch developed at the axils of major veins on the abaxial surface of chilli leaves showed significant variation among the different varieties of the chilli plants (Fig. 2.9). Table 2.2. presents the details on the average number of predatory mites, average number of trichomes and the characteristics of the pouch visible at the junction of leaf veins in different varieties of chilli plants. It was observed that the domatinal characteristics of chilli leaves such as the number of trichomes and the nature and size of pouches developed at the leaf axils exerted a positive influence on the number of predatory mites, i.e. leaves carrying more number of trichomes and well developed pouches were found to house more number of predatory mites.

II. Predatory potential of *Lasioseius (Lasioseius) moolamkudensis* sp. nov. on different life stages of *Bemisia tabaci* under laboratory conditions

The novel species of mesostigmatid predator viz. *L. (L.) moolamkudensis* sp. nov. showed affinity to feed on the various life stages of the white fly pest, *B. tabaci* such as the egg, nymph 1 and nymph 2 (Fig. 2.10), with varying range of preference. Highest preference was recorded towards the eggs, followed by the nymph 1 and nymph 2 of the white fly. In no instance, the predatory mite showed preference to feed on the nymph 3 and the pupal stage of *B. tabaci*. The mean rates of consumption shown by *L. (L.) moolamkudensis* sp. nov. on the eggs of *B. tabaci* when offered at different prey densities like 5, 10, 15 and 20 could be recorded as 3.14 ± 1.57 , 3.57 ± 1.27 , 4.71 ± 0.75 and 4.33 ± 0.57 respectively. The total consumption rate on the eggs of *B. tabaci* by the predator was recorded to be 3.87 ± 1.29 (Table 2.3). However, statistical analysis of the above data following Kruskal-Wallis test did not reveal any significant difference in the mean consumption rate of eggs in relation to prey density variations.

In the present study, data were recorded on the predatory potential of the mite towards the various life stages of the white fly pest. Accordingly, the mean consumption rates of the predator on the first nymphal stage of the white fly pest when assessed at different prey densities like 5, 10, 15 and 20 were recorded as 3.00 ± 1.00 , 3.4 ± 0.89 , 3.00 ± 1.00 and 3.67 ± 0.57 respectively (Table 2.4, Fig. 2.11). The total rate of consumption by the predator on nymph 1 of *B. tabaci* was found averaged to 3.22 ± 0.87 . Data upon statistical analysis based on Kruskal-Wallis test could not reveal any significant difference in the mean consumption rate on nymph 1 at different prey densities.

The rates of predation of *L. (L.) moolamkudensis* sp. nov. on the second nymphal stage of *B. tabaci* at different prey densities like 5, 10, 15 and 20 could be accounted as 1.40 ± 0.54 , 1.40 ± 0.89 , 1.20 ± 0.83 and 1.28 ± 0.48 respectively (Table 2.5). The total consumption rate of the predator on nymph 2 was found averaged to 1.31 ± 0.64 . However, the data on consumption rate of the predator on the second nymphal stage, at different prey densities could not reveal any significant variation when analysed through Kruskal-Wallis test.

The highest consumption rate was shown by the predator on the egg stage of *B. tabaci* (mean=3.8±1.2) followed by the nymph 1 (mean=3.2±0.8) and the lowest rate of predation was observed on nymph 2 (mean=1.3±0.7). The pupal stage was found totally rejected by the predator.

III. Evaluation of the biocontrol potential of *Lasioseius (Lasioseius) moolamkudensis* sp. nov. in the suppression of the whitefly population on potted plants

1. Estimation of population density of *B. tabaci* before and after release of the predator, *Lasioseius (Lasioseius) moolamkudensis* sp. nov.

Prior to the release of the predatory mite to the experimental set T1, the number of eggs, nymph 1, nymph 2, nymph 3 and pupa in T1 and T2 was found to be more or less similar. Upon release of *L. (L.) moolamkudensis* sp. nov. A significant reduction was observed in the number of different life stages of the whitefly in the experimental set T1 when compared to that of the experimental set T2 (Table 2.6, Fig. 2.12). As shown in the table 2.6, a 62.28% reduction in the eggs of *B. tabaci* was seen in T1 after the release of predatory mites when compared to T2. Also, 59.97%, 51.20%, 62.89% and 64.60% reduction was seen respectively in the number of life stages like nymph1, 2, 3 and pupa in the experimental set T1 after the release of the predatory mite when compared to T2 thereby indicating the biocontrol potential of the predator on the white fly population.

2. Analysis of the morphological/biochemical parameters of the test plants

a. Measurement of leaf area of chilli plants before and after the release of *Lasioseius (Lasioseius) moolamkudensis* sp. nov.

The measurements of leaf area (in cm²) recorded for the chilli plants grown in the experimental sets T1, T2 and T3 were 9.85±1.20, 9.80±1.12 and 19.75±3.79 respectively, before releasing the predatory mite, *L. (L.) moolamkudensis* sp. nov. After the release of the predatory mite, the corresponding measurements in leaf area were 19.70±1.93, 7.35±0.80 and 28.55±1.50 in T1, T2 and T3 respectively (Table 2.7, Fig. 2.13). The infestation by *B. tabaci* could record over 50% (50.12 in T1 and 50.37 in T2) reduction in the leaf area in T1 and T2 compared to T3 owing to infestation by the whitefly. It was also noted that the release of predatory mites caused a 168.02%

increase in leaf area in the experimental set T1 when compared to set T2. The differences in the values recorded were found statistically significant when subjected to Mann-Whitney U test ($p < 0.05$).

b. Analysis of moisture content of chilli leaves before and after release of the predatory mite, *Lasioseius (Lasioseius) moolamkudensis* sp. nov.

Quantitative studies on the alterations in the moisture content of chilli leaves before and after infestation by the white fly, *B. tabaci* enabled to record a considerable reduction in the infested leaves. The values recorded for the mean moisture content of chilli leaves in the experimental sets T1, T2 and T3 before the release of the predatory mite were $68.66 \pm 0.48\%$, $68.36 \pm 0.68\%$ and $75.09 \pm 0.31\%$ respectively whereas the values after the release of predatory mite were $71.96 \pm 0.85\%$, $66.04 \pm 0.26\%$ and $76.96 \pm 0.27\%$ respectively (Table 2.7, Fig. 2.13). The comparison of the values recorded in T1 and T2 with T3 before the release of predatory mites revealed more than 8% (8.56 in T1 and 8.96 in T2) reduction in moisture content in the leaves infested with whiteflies. The moisture content of the chilli leaves showed 8.96% increase in T1 after the release of predatory mites when compared to T2. The mean variations recorded in the moisture content were found statistically significant using Mann-Whitney U test ($p < 0.05$).

c. Estimation of photosynthetic pigments in the white fly infested chilli leaves before and after release of *Lasioseius (Lasioseius) moolamkudensis* sp. nov.

Results of the quantitative studies on the concentration of photosynthetic pigments (in mg/g) revealed a considerable decrease in chlorophyll a and b, total chlorophyll and carotenoids. The mean concentrations of chlorophyll a in T1, T2 and T3 before the release of *L. (L.) moolamkudensis* sp. nov. were 78.37 ± 1.38 , 78.02 ± 0.73 and 113.99 ± 1.56 respectively. The respective mean concentration of chlorophyll a in the above sets after the release of predatory mites could be recorded as 94.16 ± 2.39 , 75.39 ± 0.61 and 113.26 ± 1.134 (Table 2.8, Fig. 2.14). Thus the percentage loss of chlorophyll a in T1 and T2 due to the infestation of whiteflies was 31.24% and 31.55% respectively before the release of the predatory mite when compared to T3. But after the release of the predatory mite *L. (L.) moolamkudensis* sp. nov., a 24.9% increase was recorded in the concentration of chlorophyll a in T1. The concentration of chlorophyll b in the sets T1, T2 and T3 before the release of the predatory mite was

59.38±1.57, 58.19±3.70 and 66.18±3.03 respectively while the respective concentration after the release of predatory mite was 82.04±3.78, 60.92±1.10 and 67.10±1.51. Hence the percentage loss of chlorophyll b in the sets T1 and T2 due to the infestation by whiteflies when compared to T3 was 10.27% and 12.07% respectively before the release of the predatory mite. After the release of predatory mite in T1, 34.68% increase in chlorophyll b was noted when compared to T2. The above results hence reflected the alterations in the total chlorophyll content also.

The total chlorophyll content in T1, T2 and T3 before the release of *L. (L.) moolamkudensis* sp. nov. was 137.46±2.10, 135.93±3.19, 179.83±3.95 and after releasing the predator, the corresponding values were recorded to be 175.81±5.79, 136.02±1.17 and 180.03±1.05 respectively. Respective percentage loss of 23.55% and 24.4% could be recorded in the sets T1 and T2 due to infestation by the whitefly. Also, the total chlorophyll concentration in T1 was found increased by 29.25% after the release of the predator. A considerable loss in the concentration of carotenoids was also noted in T1 and T2 due to infestation by the whitefly, *B. tabaci*. A loss of 48.7% and 48.52% was recorded in the concentration of carotenoids in T1 and T2 sets respectively while after the release of the predator on the chilli plants in T1, 59.32% increase in the carotenoid pigments was observed. The mean concentration of carotenoids before the release of the predatory mite was 66.03±0.24, 66.25±0.36 and 128.72±0.24 while after the release, the values recorded were 101.93±0.42, 63.98±0.34 and 128.63±0.34. The above results were also found statistically significant when subjected to statistical analysis using Mann-Whitney U test with $p < 0.05$.

d. Estimation of protein content of the white fly infested chilli leaves before and after release of the predator, *Laioseius (Lasioseius) moolamkudensis* sp. nov.

The damage induced by the whitefly, *B. tabaci* was quantitatively assessed by estimating the protein concentration (in mg/g) of the chilli leaves. The respective protein contents were 319.47±4.19, 316.99±0.99 and 645.62±4.69 in the chilli plants grown in sets T1, T2 and T3 before release of the predatory mite, *L. (L.) moolamkudensis* sp. nov. After releasing the predatory mite, the protein contents in the chilli plants of T1, T2 and T3 were 576.60±3.62, 262.35±2.71 and 659.73±1.87 respectively (Table 2.7, Fig. 2.15). Hence, a loss of over 50% (50.51 in T1 and 50.9

in T2) was recorded in the protein content of chilli leaves in T1 and T2 due to infestation by the whitefly. It was also noted that the chilli leaves in T1 could replenish the protein content by 119.78% after the release of predatory mite. The above results were found statistically significant ($p < 0.05$), when subjected to Mann-Whitney U test.

e. Estimation of total phenol content in the white fly infested chilli plants before and after release of the predator, *Lasioseius* (*Lasioseius*) *moolamkudensis* sp. nov.

Unlike the primary metabolic products which showed a decrease in concentration, secondary metabolic products like the total phenol content showed an increase in concentration, owing to white fly infestation as observed in the chilli leaves studied. The phenol concentration in the sets T1 and T2 were recorded as 65.40 ± 1.57 and 65.89 ± 0.94 (in $\mu\text{mol/g}$) in the whitefly infested chilli leaves whereas that of uninfested chilli plants in T3 was 36.04 ± 0.40 prior to the release of the predatory mite. The percentage increase in the phenol content could be recorded as 81.46% and 82.82% in infested leaves of T1 and T2 respectively when compared to T3. After the release of the predator, the phenol content in T1, T2 and T3 were 38.36 ± 0.98 , 71.24 ± 0.82 and 35.52 (Table 2.7, Fig. 2.15). This indicated a 46.15% decrease in the phenol content of chilli leaves in T1. The above results were found statistically significant using Mann-Whitney U test with $p < 0.05$.

Table 2.1. Leaf area consumed (cm²) by the rice grasshopper on successive days of survival on paddy plants along with data on mortality in the control (mite free) and experimental (mite infested) sets

Feeding period (days)	Leaf Area consumed by Infested Grasshoppers(cm ²)	Number of mite Infested Grasshoppers survived	Number of mite infested Grasshoppers dead	Leaf Area consumed by Uninfested Grasshoppers(cm ²)	Number of Uninfested Grasshoppers survived	Number of Uninfested Grasshoppers dead	% change in leaf area consumed by infested grasshoppers over uninfested grasshoppers
Day 2	112.93	20	0	114.36	20	0	-1.25
Day 4	124.13	20	0	119.26	20	0	4.08
Day 6	130.80	20	0	118.13	20	0	10.72
Day 8	145.73	20	0	117.33	20	0	24.20
Day 10	132.13	20	0	117.06	20	0	12.87
Day 12	112.06	20	0	117.23	20	0	-4.41
Day 14	102.31	20	0	116.68	20	0	-12.31
Day 16	76.54	20	0	116.87	20	0	-34.50
Day 18	54.81	18	2	114.25	20	0	-52.02
Day 20	35.75	15	3	116.38	20	0	-69.28
Day 22	16.13	10	5	114.32	20	0	-85.89
Day 24	12.35	5	5	118.15	20	0	-89.54
Day 26	2.18	1	4	102.20	17	3	-97.86
Day 28	0.56	1	0	99.54	15	2	-99.43
Average	75.60*			114.27*			-33.84

*Statistically significant using Wilcoxon Signed Rank Test with $p < 0.05$ ($p = 0.040$)

Table 2.2. Population density of predatory mites in relation to leaf domatia characteristics in different varieties of chilli plants

Sl. No.	Chilli variety	Average number of trichomes (1cm ²)	Nature of Pouch at the junction of leaf vein	Mean of predatory mite population per leaf
1.	<i>Capsicum frutescens</i> LV*1	76±0.82	Well developed	2.66±0.57
2.	<i>Capsicum frutescens</i> LV2	86.33±5.50	Well developed	2±0.32
3.	<i>Capsicum frutescens</i> LV3	75±3.55	Well developed	2±0.60
4.	<i>Capsicum frutescens</i> LV4	9.33±1.52	Poorly developed	Nil
5.	<i>Capsicum frutescens</i> LV5	14.33±0.11	Poorly developed	Nil
6.	<i>Capsicum annuum</i> LV6	1.33±0.15	Poorly developed	Nil
7.	<i>Capsicum annuum</i> LV7	12±0.54	Poorly developed	Nil
8.	<i>Capsicum annuum</i> LV8	89±3	Well developed	5.33±0.57
9.	<i>Capsicum annuum</i> LV9	71±2.21	Well developed	3.33±0.55
10.	<i>Capsicum annuum</i> LV10	46±2.11	Well developed	3±0.57

*Local variety

Table. 2.3. Mean consumption rate at different prey densities of the egg stage of *Bemisia tabaci* by the predatory mite, *Lasioseius* (*Lasioseius*) *moolamkudensis* sp. nov.

Prey density	Mean	Std. Deviation
5	3.14	0.57
10	3.57	0.27
15	4.71	.56
20	4.33	.57
Mean	3.87	0.595

Table. 2.4. Mean consumption rate at different prey densities of nymph 1 of *Bemisia tabaci* by the predatory mite, *Lasioseius (Lasioseius) moolamkudensis* sp. nov.

Prey density	Mean	Std. Deviation
5	3.00	0.42
10	3.4	0.69
15	3.00	0.25
20	3.67	0.57
Mean	3.22	.5782

Table. 2.5. Mean consumption rate at different prey densities of nymph 2 of *Bemisia tabaci* by the predatory mite, *Lasioseius (Lasioseius) moolamkudensis* sp. nov.

Prey density	Mean	Std. Deviation
5	1.4000	0.54
10	1.4000	0.64
15	1.2000	0.42
20	1.2857	0.48
Mean	1.3182	0.5433

Table. 2.6. Population parameters of the life stages of *Bemisia tabaci* before and after the release of the predatory mite (in number)

Life stages	Before release of predatory mite			After release of predatory mite		
	T1	T2	% change in T1 over T2	T1	T2	% change in T1 over T2
Egg	18.33±1.52*	17.66±1.52*	3.79	8.66±0.57*	23.33±3.05*	-62.88
Nymph 1	12.64±2.08*	12±1*	3.62	5.34±1.52*	13.34±2.08*	-59.97
Nymph 2	12.33±1.52*	11.33±1.52*	5.66	6.67±0.48*	13.67±2.51*	-51.20
Nymph 3	11±2*	11.33±1.15*	-1.86	4.33±1.42*	11.67±1.50*	-62.89
Pupa	8.33±2.08*	8.52±1.05*	-1.07	3.67±1.52*	10.37±1.52*	-64.60

T1- Whitefly infested chilly with subsequent release of predatory mites, T2- Whitefly infested chilly without subsequent release of predatory mites

*Statistically significant using Mann-Whitney U test with $p < 0.05$

Table 2.7. Alterations in the biochemical and leaf area parameters before and after the release of predatory mite

Parameter	Before release of predatory mites					After release of predatory mites					
	T1	% change in T1 over T3	T2	% change in T2 over T3	T3	T1	% change in T1 over T3	% change in T1 over T2	T2	% change in T2 over T3	T3
Protein (mg/g)	319.47±4.19*	-50.51	316.99±0.99*	-50.90	645.62±4.69	576.60±3.62*	-12.60	119.78	262.35±2.71*	-60.23	659.73±1.87*
Total phenol (mg/g)	65.40±1.57*	81.46	65.89±0.94*	82.82	36.04±0.40	38.36±0.98*	7.99	-46.15	71.24±0.82*	100.56	35.52±0.33*
Moisture content (%)	68.66±0.48*	-8.56	68.36±0.68*	-8.96	75.09±0.31	71.96±0.85*	-6.49	8.96	66.04±0.26*	-14.18	76.96±0.27*
Leaf area (cm ²)	9.85±1.20*	-50.12	9.80±1.12*	-50.37	19.75±3.79	19.70±1.93*	-30.99	168.02	7.35±0.80*	-74.25	28.55±1.50*

T1- Whitefly infested chilly with subsequent release of predatory mites, T2- Whitefly infested chilly without subsequent release of predatory mites, T3-Uninfested chilly

*Statistically significant using Mann-Whitney U test with $p < 0.05$

Table. 2.8. Concentration of photosynthetic pigments in chilli leaves before and after release of the predatory mites

Chlorophyll pigments (mg/g)	Before release of predatory mites					After release of predatory mites					
	T1	% change in T1 over T3	T2	% change in T2 over T3	T3	T1	% change in T1 over T3	% change in T1 over T2	T2	% change in T2 over T3	T3
Chlorophyll a	783.72±1.38*	-31.24	780.25±0.73*	-31.55	1139.91±1.56	941.63±2.39*	-16.86	24.90	753.90±0.61*	-33.43	1132.62±1.134
Chlorophyll b	593.82±1.57*	-10.27	581.94±3.70*	-12.07	661.85±3.03	820.49±3.78*	22.27	34.68	609.21±1.10*	-9.212	671.03±1.51
Total chlorophyll	1374.64±2.10*	-23.55	1359.36±3.19*	-24.40	1798.32±3.95	1758.17±5.79*	-2.34	29.25	1360.25±1.17*	-24.44	1800.32±1.05
Carotenoids	660.37±0.24*	-48.7	662.58±0.36*	-48.52	1287.27±0.24	1019.35±0.42*	-20.75	59.32	639.81±0.34*	-50.26	1286.34±0.34

T1- Whitefly infested chilly with subsequent release of predatory mites, T2- Whitefly infested chilly without subsequent release of predatory mites, T3-Uninfested chilly

*Statistically significant using Mann-Whitney U test with $p < 0.05$

Chapter 10

Discussion

Mites and insects are well designated as the hyper diverse groups of animals, frequently exhibiting spatial and temporal co-occurrence, which often has resulted in the evolution of diverse types of symbiotic, antagonistic, commensalistic, and mutualistic interactions between them. Specific studies on such relationships between mites and insects are extremely important in order to procure knowledge on the of the functioning of many communities, as well as the evolution of these two groups of arthropods, which in turn would help to formulate practical application on the manipulation of their populations such as the biological control of arthropod pests. Of the varied kinds of associations exhibited by mites with their insect hosts, two types viz. the parasitic and predatory modes of interactions have been focussed in detail in the present part of the thesis, in order to elucidate their biological impact in the population suppression of respective insect pests (hosts). Accordingly, giving due consideration to their agricultural relevance, two well known species of highly polyphagous insect pests viz. the rice grass hopper, *O. hyla* and the notorious white fly pest, *B. tabaci* the tobacco white fly were selected as the respective insect hosts for detailed exploration of biological control using their common, most abundant and novel species of mite associates identified during the study viz. *P. palappuramensis* sp. nov. and *L.(L.) moolamkudensis* sp. nov. representing parasitic and predatory types of associations respectively.

Biological control, being a key ecosystem service and an underlying pillar of integrated pest management (Naranjo *et al.*, 2015), gained wide global attention and in many parts of the world, it has become the common practice as part of the IPM strategy especially in greenhouse conditions against insects and mites (Knapp *et al.*, 2018). Of the 219 species of commercially available arthropod species of biocontrol agents listed by Van Lenteren (2012) more than half were Hymenoptera (52.2%) followed by Acari (13.1%), Coleoptera (12.2%) and Heteroptera (8.3%). Of these, biological control of insects employing acarines is achieved by exploiting the associations of mites such as predation, parasitism, parasitoidism and disease

transmission to bring out adequate levels of suppression of pest populations and maintain the pest number below economic injury level (Gerson *et al.*, 2003).

In the present study, impact of a novel species of ectoparasitic mite viz. *P. palappuramensis* sp. nov. was studied in detail by making studies on the general vigor, behaviour, feeding activity and damage induced by the grass hopper, *O. hyla* maintained on paddy plants in the experimental (mite infested) and control (mite free) set ups and by measuring the lamina area consumed by the grass hoppers in experimental and control set ups for a period of 29 days and comparing the differences between the two. The study revealed that parasitism by *P. palappuramensis* sp. nov. adversely affected the feeding activity and longevity of *O. hyla*. It was observed that for the first 1-3 days the feeding activity of the mite infested and uninfested grasshoppers was more or less similar, as the measurements of the fed area in the experimental and control sets were comparable and on the 4th day onwards an increase in the leaf consumption was seen in the infested grasshoppers up to the 12th day followed by a decrease in the feeding activity from days 12-28. The parasitized grasshoppers were found to consume even 24.2% more than the uninfested ones on days 7-9. On the day 10, a 12% increase in the feeding activity of parasitized grasshoppers was observed which was found less than that of the previous days (7-9). This was followed by a decline in the consumption by parasitized grasshoppers. On an average, it was found that the parasitisation resulted in 33.84% decline in consumption in infested grasshoppers compared to that of the uninfested grasshoppers. It was also observed that as parasitisation progressed on the host grasshoppers, they exhibited a lethargic behaviour, loss in vigour and were found sluggishly hiding among the leaves, and not seen to come to the exposed leaves of paddy plants at the upper surface, unlike the active feeders in the uninfested group. The longevity of the parasitized grasshoppers was also found reduced when compared to the mite free grasshoppers. In the experimental set up, 100% mortality was observed on the 29th day while in the control group, the last individual survived till the 36th day. The altered feeding behaviour, reduced longevity and loss in vigour may be possibly due to the feeding of haemolymph by the parasitic mites. This was very evident in the case of adult female of *P. palappuramensis* sp. nov. where the adult females were found attached to the abdominal tergites with the help of mouthparts. Their modified mouthparts were found to make incisions on the host body so as to

suck the haemolymph. The present observations were found in agreement with earlier studies on the occurrence of wide range of feeding alterations ranging from decreased to increased feeding behaviour recorded in invertebrate hosts infected with *Nosema* (Moore, 1993). Insects like the sand flies and mosquitoes infected with *Leishmania* and malarial parasites were also known to exhibit altered feeding behaviour which force them to make many feeding attempts, each time depositing parasites at the feeding site. This can be considered as an adaptive mechanism of the parasite to promote the rate of parasitisation (Hurd, 2003). The increased density of parasites such as *Plasmodium* spp. was reported to decrease the survivorship of mosquitoes of the genus *Anopheles* (Gad *et al.*, 1979; Klein *et al.*, 1982).

Parasitized hosts were reported to exhibit reduced rates of survival or reproduction and which could be attributable to direct causes such as the detrimental effects of the parasite on a host or the reduced resource availability resulting from parasitism or, indirect causes like the costs of immune system activation (Moret and Schmid-Hempel, 2000; Hurd, 2001). The results of the present study disclosed that *P. palappuramensis* sp. nov. exerted a profound impact on the survival and longevity of *O. hyla* maintained in the experimental set up when compared to the healthy, mite free individual of the control set up. The mite infested grasshoppers (experimental set up) were subjected to early mortality and undergone death on the 18th day whereas the mite free grasshoppers survived upto the 29th day. Mite free grasshoppers in the control set up, mortality occurred on the 26th day and the last grasshopper survived upto the 36th day. This observation on the reduced survival status of mite infested grasshoppers is in agreement with the earlier findings of Belovsky *et al.* (1997) which recorded a mean reduction of 29% in the survival of grasshopper nymphs and adults due to infestation by parasitic mites and further the female reproductive output was found reduced by an average of 47 %. Similar records on reduced longevity also exist in the case of tse-tse flies infected with *Trypanosoma* spp. (Maudlin *et al.*, 1998) and in the green stink bug, *Nezara viridula* infected by *Trichopoda pennipes* (Harris and Todd, 1982). However, contradictory observations on the enhanced feeding rate due to parasitism were also made on the cassava mealy bug (Calatayud *et al.*, 2001). There is an interesting case of altered feeding behaviour reported by De Roode and Lefevre (2012) where the insect caterpillars feed on toxic plants to combat parasitic infection which is a form of behavioural immunity.

The present observation on the interference of the parasitic podapolipid members with the activities of host grass hoppers supports the findings of Gauchat (1972) on the loss in vigour of the Australain locust, *Chortoicetes terminifera* owing to infestation by the parasitic mite, *Podapolipoides grassii*. The infested locusts were found to be less active and were easily cannibalised by other locusts. Smiley (1974) erected a new species of ectoparasitic mite, *Coccipolipus epilachnae* on Mexican bean beetle and reported that parasitism by the species resulted in reduced egg production. Parasitism by *C. epilachnae* was also known to reduce the oviposition of its beetle host, *Epilachna varivestis* by 66.2% and increased its mortality by 44% (Schroder, 1982). Based on the high host specificity exhibited by *C. epilachnae* towards the insects belonging to subfamily Epilachninae, Schroder (1979) suggested its introduction for the biocontrol of the Mexican bean beetle. However, contradicting the above findings, Cantwell *et al.* (1985) reported that no significant difference could be recorded in the longevity, fecundity and feeding between the uninfested and infested beetles. Another podapolipid member, *Coccipolipus hippodamiae* was found to be a carrier of sexually transmitted disease in *Adalia bipunctata*. The mite reduced the egg production in the affected females and also less viable eggs were produced by affected females (Hurst *et al.*, 1995). A similar contradictory observation was made by Baker and Eickwort (1975) also which disclosed that the adult females of the podapolipid species, *Chrysomelobia labidomerae* parasitising the milkweed beetle, *Labidomera clivicollis* did not noticeably affected the longevity and fecundity of their hosts. Despite the above reports, in the present study a negative impact was evident due to infestation by the novel species of the podapolipid species viz. *P. palappuramensis* sp. nov. on the vigor, feeding activity, survival as well as longevity of its grass hopper host, viz. *O. hyla*.

During the present study, attention was also focussed to trace the impact of another type of insect-mite association such as predation towards the control of insect pest population. For the last few decades, predatory mites have attracted public attention owing to their practical use in pest control programmes of arthropod pests such as the insects and mites. Among the various families of predatory mites, members of the family Phytoseiidae have been widely used as the main predators of phytophagous mites and some small insects like the thrips, white flies, scale insects etc. inhabiting the aerial plant parts (Mc Murtry *et al.* 2013). Other than the phytoseiid predators,

many others await their discovery for practical use against agricultural pests, of which the families Ascidae, Blattissociidae etc. deserve special mention. Most of the plant associated blattissociids belongs to the genus *Lasioseius* and nearly 27% of the species of this genus were described from plant parts from all over the world (Moraes *et al.* 2015). Several species of *Lasioseius* were reported to complete development on varied types of insect preys (Nawar *et al.* 1990; Abou-Awad *et al.* 2001; Mowafi, 2005; Wu *et al.* 2009; Xu, 2011). Duly considering the heavy infestation of chilli plants by the tobacco white fly, *B. tabaci* and the close association of a novel predatory species of *Lasioseius* viz. *L. (L.) moolamkudensis* sp. nov. with the white fly population, feeding experiments were carried out to ascertain the nature of their association.

Results of feeding experiments carried out in the laboratory revealed the feeding preference of *L. (L.) moolamkoodensis* sp. nov. to the eggs and first two nymphal stages of *B. tabaci* and hence further studies were undertaken to elucidate its predatory potential on the white fly population. It was observed that among the three preferred life stages of *B. tabaci*, primary preference was shown by the predator to the egg stage of the white fly followed by nymph 1 and nymph 2. The results of statical analysis of the data recorded on feeding experiments could not reveal any significant variation in the consumption rates of *L. (L.) moolamkudensis* sp. nov. in relation to varying densities of the white fly life stages, indicating that the predation is not affected by the prey density.

L. (L.) moolamkudensis sp. nov. was found to exert a significant reduction in the *B. tabaci* population under controlled conditions in potted plants. Though the genus *Lasioseius* is less known as predator of whiteflies, its nematophagous habit has been well established (Cayrol, 1970; Imbriani and Mankau, 1983). Some of the species were reported to be prominent predators of pest mites as in the case of *L. parberlesei* on *Steneotarsonemus spinki* infesting rice (Tseng, 1984) and *L. chaudhrii* on *Tarsonemus bilobatus* (Zhang and Fan, 2010). Walter and Lindquist (1989) discussed the omnivorous feeding habit of *Lasioseius* spp. and the authors reported that the cheliceral parts of the genus are modified to feed on both fungus and small invertebrates. Some of the species of *porulosus* group in the genus *Lasioseius* were known to carry fungal spores attached to their cuticle (Walter and Lindquist, 1997). The present observation on the occurrence of fungal spores attached to the cuticle of *L. (L.) moolamkudensis* sp. nov. serves to support the above finding. Probably, this

may be indicative of mycophagous habit of the species as already reported (Walter and Lindquist, 1989). Since many species of *Lasioseius* are known to be omnivorous, exhibiting a wide range of feeding preferences from fungi to small invertebrates like nematodes and mites, Britto *et al.* (2012) tested the efficacy and feeding preferences of *L. floridensis* to advocate the mite for the biocontrol of broad mite, *Polyphagotarsonemus latus*. It was found that though the mites consumed the broad mite, *L. floridensis* performed much better on a diet comprised of the nematode, *Rhabditella axei*. However, in the present study, no such feeding preference test was performed. Since the predatory mite, *L. (L.) moolamkudensis* sp. nov. performed better on the potted plants, it can be speculated that *B. tabaci* constitutes a preferred prey to the predator. The presence of fungal spores attached to the cuticle of the predatory is suggestive of its possible mycophagous habit, but a more legitimate conclusion would be that the honeydew secreted by whiteflies urge the fungal growth, which in turn tends to stick on the cuticle of the mite.

In order to evaluate the potential of *L. (L.) moolamkudensis* sp. nov. as a biocontrol agent of the whitefly pest, *B. tabaci*, comparative studies on various parameters such as the population density, leaf area consumption, moisture content, photosynthetic pigments, protein and phenol contents of potted plants etc. were made in the experimental and control set ups. The results of the study helped to record a reduction in the moisture content, leaf area, protein and photosynthetic pigments of leaves infected with *B. tabaci* when compared to those of the control plants. Infestation by *B. tabaci* was found to cause more than 8% reduction in the moisture content of chilli leaves than the uninfested set. After the release of the predatory mite, *L. (L.) moolamkoodensis* sp. nov. , 8.96% increase was observed in the moisture content of chilli leaves in the experimental leaves. Further, infestation by *B. tabaci* induced over 50% reduction in the leaf area and after release of the predatory mite, 168% increase was observed in the leaf area of chilli plants in the experimental set up. It was observed that the whitefly infestation could induce over 50% reduction in the protein content of chilli leaves, while the release of the predatory mite in experimental plants helped to replenish the protein content by 119%. A significant reduction was recorded in the photosynthetic pigments also by accounting 24% reduction in the total chlorophyll content in the whitefly infested plants when compared to that of the uninfested set. In response to the release of the predatory mite, the total chlorophyll content showed an

increase by 29% in the experimental set. A considerable loss (48%) in the concentration of carotenoids was also noted in the whitefly infested sets and after the release of the predator on the infested chilli plants, the carotenoids showed an increase by 59.32%. The above observations clearly attest the potential of the predator, *L. (L.) moolamkudensis* sp. nov. as a promising biocontrol agent, by efficiently suppressing the white fly population and ensuring the vigor and vitality of crop plants.

The observation made during the present study on the reduction in the leaf area of chilli leaves seems to support the earlier finding of Cohen and Antignus (1994), where the authors reported severe stunting of plant growth and misshapen of leaves in tomato plants due to silverfly infestation. The present findings on the reduction in the leaf area, photosynthetic pigments and moisture content are in agreement with the previous observations of Islam and Shunxiang (2009) and Yang *et al.* (2011) on the significant variation in several leaf parameters like leaf area and moisture content, chlorophyll content and rate of photosynthesis in egg plants and pepper plants infested with *B. tabaci*. The whitefly infested leaves displayed significantly lower contents of photosynthetic pigments and protein when compared to the uninfested leaves, as revealed by the present study also. This was found true in the case of moisture content also, where the whitefly infestation induced 7% reduction in moisture content. The above results are in support of the earlier findings of Jetter *et al.* (1997) on the reduced photosynthetic pigments recorded in several crops in California and Mc Auslane *et al.* (2004) on the reduced photosynthetic pigments and plant size owing to infestation by *Bemisia argentifolii* in different varieties of *Cucurbita pepo*. A similar reduction in the protein content, moisture, nitrogen, phosphorus and potassium was observed in cassava leaves also due to infestation by *B. tabaci* as revealed through the studies made by Antony and Palanisami (2006) and Sakthivel (2018) in India.

Significant variations in the physiological parameters like chlorophyll content and morphological parameter like leaf area owing to infestation by *B. tabaci* were previously recorded by various authors. Islam and Shunxiang (2009) stated that *B. tabaci* being a phloem feeder could reduce the productivity of the egg plant by direct consumption. Similar leaf damages like the reduced photosynthetic pigments, protein, moisture content, leaf area, soluble proteins, free amino acids, sugar and phenol were found induced by the infestation of other species of whiteflies such as *Aleurodicus disperses* as revealed through the studies made by Mahadeva (2016) in mulberry

leaves. Infestation by the spiraling whitefly on coconut leaves was found to induce alterations in some biochemical parameters as well as reducing the photosynthetic efficiency of the plant as evidenced through the studies of Arun *et al.* (2021). Li *et al.* (2021) found that both the adults and nymphs of *B. tabaci* removed sap from the phloem and thereby resulting in a reduction in the moisture and protein contents as well as the leaf area of host plants. The reduction in the photosynthetic pigments would hamper the photosynthetic process and bringing down the yield of host plants. The photosynthetic efficiency of the host plants would be further hampered by the excretion of honeydew by the white flies, inviting fungal growth that stains the leaf as pointed out by Horowitz *et al.* (2020).

The present study also helped to record significantly higher content of total phenol in the whitefly infested leaves when compared to the uninfested leaves of chilli plants. The infested plants showed over 65% increase in phenol and upon release of the predatory mite, more than 80% reduction in phenol content was observed in the plants of the experimental set. Whitefly infestation was reported to alter the leaf phenol content as recorded by Marmit *et al.* (2008) and elevated levels of phenol play an important role in defense against herbivory as suggested by Appel (1993). Phenolic compounds would serve to impede the feeding activity by forming non digestible clathrates in insects, inactivating enzymes in the insect gut, causing oxidative damage and finally leading to the death of insect (Harborne, 1999). Usha Rani and Jyothsna (2010) also pointed out that secondary metabolites like phenols, condensed tannins and hydrogen peroxide would act as defensive enzymes. Some phenolic compounds act as feeding deterrents, growth inhibitors and toxins also (Zhang *et al.*, 2017). These secondary metabolites combat the biotic and abiotic stresses (Tak and Kumar, 2020). The elevated phenolic level in the whitefly infested plants observed in the present study is undoubtedly is a result of biotic stress induced by *B. tabaci* and it supports the earlier observations of Srinivasan and Uthamasamy (2004) on 1.50-3.00 fold increase in the phenol content of tomato leaves due to infestation by *B. tabaci* and of De Lima Toledo *et al.* (2021) on similar increase in the concentration of phenolic compounds in whitefly infested leaves of tomato.

The release of *L. (L.) moolamkudensis* sp. nov. on to the experimental set T1 revealed that this predatory mite could significantly bring down the severity of infestation by the whitefly, *B. tabaci*. The amount of leaf moisture, leaf area, protein and

photosynthetic pigments in T1 plants were significantly higher than those of the control set T2, after the release of predatory mites on to T1 plants. During the study, the number of different growth stages of the whitefly from egg-pupa were also calculated in both sets T1 and T2 before the release of predatory mite. After the release of the predatory mite on to T1, a significant difference was observed in the number of each growth stage of the whitefly ie, the number of different life stages of the whiteflies was significantly lower in T1 when compared to T2. This observation revealed that *L. (L.) moolamkudensis* sp. nov. could act as a promising biocontrol agent of *B. tabaci* infesting chilli. Considering the dearth of experimental studies on the relationship of *Lasioseius* spp. with other insect groups with exception of highly scattered information on an unidentified species of the genus on *B. tabaci* (Wu *et al.* 2009; Xu, 2011), it is hightime to initiate attempts to explore much on the feeding attributes of the members of the genus towards the control of insect pests. The present study therefore forms the first record on a novel species of *Lasioseius*, being employed as a successful biological control agent against the whitefly, *B. tabaci*.

In the present study, attention was also focused to determine the factors which govern the population density and abundance of predatory mites exhibiting association with the white fly population infesting chilli plants. It was observed that the population density and abundance of predatory mites varied in relation to leaf domatia characteristics in different varieties of chilli plants. Significant variation was observed among the characteristics of leaf domatia such as the number of trichomes and the size and appearance of the pouch developed at the axils of major veins on the abaxial surface of chilli leaves present in the 10 varieties of chilli plants selected for the study. The leaves carrying more number of trichomes and well developed pouches were found to house more number of predatory mites. Accordingly, the local variety (LV8) of *C. annuum* hosted more number of predatory mites. Chilli plant varieties with the leaves bearing lesser number of trichomes and poorly developed were found to harbour lower number or occasionally complete absence of predatory mites. Leaf trichomes form an important leaf component which acts as a curse and boon for the plants. While they negatively affect the activity of hymenopteran parasitoids they have positive influences on predatory mites. Keller (1987) recorded a reduced walking speed of *Trichogramma exiguum* with an increase in trichome density and De Ponti *et al.* (1988) reported a decrease in the rate of parasitoidism by *E. formosa* decrease

with an increase in the number of trichomes. Contracting the above, Downing and Moilliet (1967) attributed a positive effect of trichome density in determining the populations of predatory mites like *Metaseiulus occidentalis* and *Neoseiulus caudiglans* in different varieties of apple trees where as Krips *et al.* (1999) made a contrasting observation that walking speed of predatory mite, *Phytoseiulus persimilis* increased with a decrease in hair density. The results of the present study supports the findings of Downing and Moilliet (1967) by recording higher number of the predatory mites on chilli varieties bearing comparatively higher number of leaf trichomes.

Leaf structures like acarodomatia serve to provide shelter to predatory mites and thereby forming important component indetermining predatory mite abundance (Lundstrom, 1887). O'Dowd and Willson (1989) defined domatia as leaf structures like pits, pouches, pockets and tufts of trichomes found at the junction of leaf veins. In this way the trichomes taken into consideration in the present study also could be considered as an integral component of acarodomatia. Walter (1996) attributed that the domatia measure one or two millimeter in diameter. Leaf domatia influence the abundance of predatory mites in several ways. They decrease the wettability of leaf tissues and thereby helping to avoid the effect of non target pesticides as attributed by by Xu *et al.* (2010). In the present study it was found that domatia carried more number of predatory mites and their eggs were well visible to be adhered to the tuft of trichomes, and which would become advantageous by providing additional benefits like providing favourable microhabitat for sheltering the predatory mites, substratum for egg laying, offering protection from other natural enemies, avoiding the chances of getting overexposed to the extremes of climatic factors, thereby supporting the findings of Sabelis (1981) that the dense trichomes would offer suitable ground for egg incubation and also offer protection from predators. Plants like cassava are also known to develop pseudodomatia to shelter predatory mites (Grostal and O' Dowd, 1994). The presence of extrafloral nectaries on leaves can influence the abundance of predatory mites (Bakker and Clein, 1992) since they can serve as a source of moisture, carbohydrates and amino acids. Contradictory to the above, Walter (1996) in his review mentioned that the glandular hairs on most of the leaves negatively affect the number of mites, as some glandular trichomes can make toxic compounds that kill the predators as pointed out by Levin (1973) and Kennedy (2003). The study therefore recommends the need for developing plant varieties by

incorporating all desirable features to promote the sheltering and population build up of important natural enemies as a prerequisite to prevent herbivory.

Summary

Mites exhibit various types of associations with other vertebrate and invertebrate animal groups, and among the latter, insects form the principal group. Insect-mite interactions might have developed due to sharing of common habitats and hence are possibly accidental. The incidence and extent of the interaction vary considerably, depending on the morphological and biological diversity of the mites as well as the insect hosts involved. By co-existing in the same habitat and sharing the common dietary resources, mites have established more complex types of associations with insects, which may be of temporary nature, to enjoy passive dispersal or may be commensalistic, mutualistic, parasitic or predatory. Of the different types of associations met among insects and mites, parasitism and predation can successfully be exploited in biological control of insect pests and hence, insect associated mites have received importance. The present work was therefore taken up to explore the diverse fauna of mites associated with some selected species of insects of agricultural importance, in order to study their distribution pattern on respective insect hosts, to explore the nature of association on respective hosts, to identify the different life stages of mites associated with the insect hosts and to explore the potential of parasitic/predatory mites to suppress the population of selected species of insects. With these objectives, the present study forms the first of its kind in Kerala and it serves to add more information on the insect-mite associations in India, so far gathered from other Indian states like West Bengal, Tamil Nadu and Haryana.

During the present study, insects belonging to 25 genera, 14 families and five orders of insects viz. Coleoptera, Orthoptera, Hemiptera, Blattodea and Lepidoptera were collected from 29 sampling localities distributed across four districts of Kerala viz. Thrissur, Palakkad, Kozhikode and Malappuram. The mites collected from the various body parts of insects were preserved in 70% alcohol and were subsequently dehydrated by passing through 80%, 90% and absolute ethanol series. The weakly sclerotised specimens were directly slide mounted in Hoyer's medium, without subjecting to dehydration and clearing procedures. Moderately/heavily sclerotized

mite specimens were transferred to a clearing medium, prepared by mixing absolute ethyl alcohol and lactic acid in the ratio of 1:1 and then slide mounted in Hoyer's medium for further taxonomic studies. Systematic position of mites was analysed by referring the identification keys available in Hughes (1976), Gupta (2003), Krantz and Walter (2009), and other relevant research publications. Drawings were made using a prism type camera lucida and scaling of individual species was done using an ocular micrometer. The final drawing of the morphological features of the specimens was made using the software Adobe illustrator. The different regions of the body of the host insect specimens were thoroughly examined under a stereozoom microscope in order to record data on the preferred sites of attachment of the various mite species, population density of the various mite taxa on the specific body parts of host insects, and the various life stages of mite associates on the different body regions of the insect hosts etc. For studying the nature of mite infestation and its impact on the body of insect hosts, detailed microscopic examination was carried out to locate the traces of feeding symptoms, if any, such as the presence of feeding punctures/ scars, oozing out of haemolymph etc. The impact of phoretic mite load on the body weight of respective insect hosts was also assessed in three representative species of major insect pests like the weevil/beetle hosts viz. *Odoiporus longicollis*, *Oryctes rhinoceros* and *Rhynchophorus ferrugineus*, by recording the difference in their body weights before and after removal of mites from all parts of their body. Laboratory rearing of a selected species of acarine associate, viz. *Histiostoma furrowa* sp. nov. which showed facultative necromeny on its host insect, *O. longicollis* was performed at a temperature of $27\pm 2^{\circ}\text{C}$ and 75 ± 3 RH, on four different media like cut piece of banana pseudostem, paper discs overlaid with yeast solution, decapitated carcass of the weevil and carcass of weevil placed on banana pseudostem.

Studies were also undertaken to explore the potential of two novel species of acarine associates in suppressing the populations of respective insect hosts. For this, the parasitic impact of *Podapolipus palappuramensis* sp. nov. infesting the paddy pest viz. *Oxya hyla* and the predatory potential of *Lasioseius (Lasioseius) moolamkudensis* sp. nov., on the various life stages of *Bemisia tabaci* were studied. The impact of parasitisation by *P. palappuramensis* sp. nov. on feeding and longevity of *O. hyla* was studied by making regular observations on mite infested and mite free specimens of the rice grass hopper, *O. hyla* reared on paddy plants maintained in netted condition.

The change in the abundance of predatory mites in relation to the leaf domatid characteristics was also studied in ten different varieties of chilli. The assessment of biocontrol efficacy of the predatory mite, *L. (L.) moolamkudensis* sp. nov. was carried out on leaf discs of chilli plants containing different stages of *B. tabaci* at various prey densities. The biocontrol efficacy of the predatory mite, *L. (L.) moolamkudensis* sp. nov. to suppress the population of *B. tabaci* was also studied on potted plants of chilli. Various parameters like population density of whiteflies, physico-chemical parameters like leaf area, moisture content, photosynthetic pigments (Chlorophyll, a, b, total chlorophyll and carotenoids), protein and phenol contents of the chilli leaves were analysed. The data gathered on the various lines of studies mentioned above have been summarized below.

During the present study, 65 species of mites belonging to 42 genera, 26 families, 19 superfamilies, 3 orders and 2 superorders under the subclass Acari were collected and described. Of the 29 insect species screened, 24 species were found to host mites. The superorder Parasitiformes was found to comprise 52% of the total species, and the rest 48% were the members of the superorder Acariformes. The most dominant superfamilies recovered under the subclass Acari were Phytoseioidea and Acaroidea, each with representation by 9 species. The study helped to contribute 10 species new to science viz. *Tridiplogynium rhynchophora* sp. nov., *Schizodiplogynium rhinocera* sp. nov., *L. (L.) moolamkudensis* sp. nov., *Pygmephorus indicus* sp. nov., *P. palappuramensis* sp. nov., *Locustacarus chinensis* sp. nov., *H. furrowa* sp. nov., *Curculanoetus keralensis* sp. nov., *Canestriniella batocera* sp. nov. and *Athogavia oryctae* sp. nov. The mites which were recorded for the first time from insect hosts could be listed as; *Uroobovella pilosetosa*, *Macrocheles perglaber*, *M. glaber*, *Neoseiulus mapuche*, *Holoparasitus stramenti*, *Lasioseius confusus*, *Hypoaspis heselhousi*, *Cheyletus kuznetsovi*, *Hoplocheylus longispinus*, *H. zanzibarensis*, *Steneotarsonemus brasiliensis*, *Histiostoma herbali*, *Rhizoglyphus vicantus*, *Acotyledon tariqi*, *T. rhynchophora* sp. nov., *S. rhinocera* sp. nov., *L. (L.) moolamkudensis* sp. nov., *P. indicus* sp. nov., *P. palappuramensis* sp. nov., *L. chinensis* sp. nov., *H. furrowa* sp. nov., *C. keralensis* sp. nov., *C. batocera* sp. nov. and *A. oryctae* sp. nov. Six phytoseiid species viz. *Amblyseius channabasavannai*, *A. largoensis*, *A. vasiformis*, *E. finlandicus*, *E. ovalis*, *T. kroeffi* and two cunaxid members like *C. heterostriata* and *C. anomala* could be reported for the first time from

chilli plants infested with *Bemisia tabaci*. The mite species like *M. muscaedomesticae*, *Histiostoma sammari*, *Congovidia glossinae*, *Tyrophagus putrescentiae*, *Procalvolia* sp., *Dinogamasus* sp., and *Laelaps* sp., *Poecilochirus* sp. formed the first report from the order Coleoptera while the mesostigmatid mite, *A. helleri* formed the first record from the order Lepidoptera. The species like *Premicrodispus paramaevi*, *Caloglyphus manuri*, *Schweibea* sp. and *Sapracarus* sp. formed first report from the order Blattodea. 59 species viz. *T. rhynchophora* sp. nov., *S. rhinocera* sp. nov., *Uropoda heliocopridis*, *U. orbicularis*, *U. shangaica*, *Uroobovella phoenicicola*, *U. pilosetosa*, *Poecilochirus* sp., *Digamasellus neodisetus*, *D. quadrisetus*, *Alliphis halleri*, *Alliphis* sp., *Macrocheles glaber*, *M. krantzi*, *M. muscaedomesticae*, *M. perglaber*, *A. channabasavannai*, *A. largoensis*, *A. vasiformis*, *E. finlandicus*, *E. ovalis*, *T. kroeffis*, *Neoseiulus mapuche*, *Lasioseius confusus*, *L. moolamkudensis* sp. nov., *Laelaps* sp., *Hypoaspis heselhousei*, *H. sardous*, *Dinogamasus* sp., *Cunaxa anomala*, *C. heterostriata*, *Leptus treati*, *Neosilphitrombium gratum*, *Cheyletus kuznetsovi*, *Hoplocheylus longispinus*, *H. zanzibarensis*, *Pavania foliata*, *Premicrodispus paramaevi*, *Pygmephorellus indicus* sp. nov., *Steneotarsonemus brasiliensis*, *P. palappuramensis* sp. nov., *L. chinensis* sp. nov., *Histiostoma herbali*, *H. maritimus*, *H. sammari*, *H. furrowa* sp. nov., *C. keralensis* sp. nov., *C. batocera* sp. nov., *A. oryctae* sp. nov., *Congovidia glossinae*, *Procalvolia* sp., *Acarus solimani*, *Rhizoglyphus vicantus*, *Acotyledon tariqi*, *Schweibea* sp., *C. manuri*, *C. subterraneousi*, *T. putrescentiae*, *Sapracarus* sp. formed new associations with the so far unreported insect hosts and 55 species formed the first report from India.

More than 50% of mite species (64%) collected were found associated with the insects belonging to the order Coleoptera, 14% showed association with Blattodea while 13% were seen in association with Hemiptera. 8% of the collected species showed association with insects of the order Orthoptera and the lowest number (1%) of mite species could be recorded from the order Lepidoptera. The rhinoceros beetle pest infesting coconut, *O. rhinoceros* was recognized as the insect host carrying the maximum number of mite species, i.e, 13 followed by *R. ferrugineus* with 10 species. Nine species of predatory mites were found associated with chilli plants infested with *Bemisia tabaci* while only one species of predatory mite was found associated with *Aleurothrixus floccosus*. The dung beetles like *Copris repertus*, *Onitis philemon* and *Catharsius molossus* were found to harbor 11 species of mites, 5 species on *C.*

repertus and 3 each on *O. philemon* and *C. molossus*. The members of Blattodea like *Odontotermes feae* and *O. obesus* carried four species of mites each while *Nasutitermes gardneri* carried three species. The orthopteran member *Oxya hyla* was found to carry four species of mites while two species were recovered from *Oxya chinensis*. Three species of mites were recovered from the beetle pest of mango viz. *Batocera rufomaculata*. Two species of mites were collected from the coleopteran insect pests like *O. longicollis*, *Cosmopolites sordidus*, *Aulacophora foveicollis*, *Henosepilachna vigintioctopunctata*. The least number of mite species was found on insects like *Xystocera globosa*, *Aulacophora frontalis*, *Hoplasoma unicolor*, *Altica* sp., *Gonocephalus* spp. and *Melanitis leda ismene*. Of the various species of mites collected from insects, 28 species were recovered as adult females, 27 as deutonymphs, six species as adult males, two in their larval stage and one in its protonymphal stage. All the life stages were recovered in the case of five species of mites from the body of their insect hosts. 76% of the insect-mite association was found to be phoretic. Majority of the phoretic members were from the order Mesostigmata (27 spp.) followed by 15 spp. from the order Sarcoptiformes. 13% of the insect-mite association was predatory, all of which was from the order Mesostigmata. 10% of the insect-mite association was parasitic in nature (6 spp.), and comprised of species belonging to orders Trombidiformes and Sarcoptiformes. Only one species, *H. furrowa* sp. nov. exhibited facultative necromeny on its host, *O. longicollis*. The insect order Coleoptera showed association with 52 species, maximum of which was phoretic type (47), four were found to be parasitic and one species exhibited necromeny. In the order Blattodea, all the 11 species showed phoretic association. The type of association shown by all the 10 species of mites with members of the order Hemiptera was found to be predatory in nature. Out of the six species of acarines associated with members of the order Orthoptera, four were ectoparasitic and two were phoretic in nature. The single insect-mite association observed in the order Lepidoptera was found phoretic in nature. 20% of the mites collected during the study showed no specific preference to particular body region of their insect hosts. Among the mite spp. that preferred a specific body part of their insect hosts, 17% preferred abdominal ventrites followed by the head region. Detailed studies on the phoretic load of mites on different body parts of host insects revealed that the most preferred body region was abdominal ventrites followed by subelytra. The highest percentage of occurrence as well as prevalence among the adult insect was exhibited by *O.*

longicollis which was 91.8% while *Altica* sp. exhibited lowest percentage of occurrence. The mean intensity was found to be highest in *C. batocera* sp. nov. on *B. rufomaculata* followed by *P. foliata* on *C. molossus*. Measurement of phoretic load of mites on insect hosts like *O. longicollis*, *O. rhinoceros* and *R. ferrugineus* revealed that the body weight of the insect with mites was significantly less than the body weight of the insect without mites.

The deutonymphs of *H. furrowa* sp. nov. molted into their tritonymphal stage within 2-3 days after they were placed on the weevil carcasses, whereas the duration of which was found extended to 5-6 days when placed on yeast solution and pseudostem. The duration of the various developmental stages of the species when recorded in hours were; egg-larva (42.3 ± 0.67), larva (24.2 ± 0.32), Larval quiescence (9.8 ± 0.78), Protonymph (24.3 ± 0.27), Protoquiescence (6.5 ± 0.23), Deutonymph (31 ± 4.7 (on weevil carcass) 133.73 ± 7.74 (on pseudostem and yeast solution), Deutoquiescence (7.3 ± 0.2), Tritonymph (23.2 ± 0.27), Tritoquiescence (6.7 ± 0.24). The pre-oviposition, oviposition and post-oviposition periods lasted for 28.6 ± 0.7 , 47 ± 1.45 and 72.7 ± 1.24 hours respectively. The average number of eggs laid per female was 15.2 ± 1.87 . The deutonymphs of *H. furrowa* sp. nov. were known to exhibit facultative necromeny. The life cycle studies of *H. furrowa* sp. nov. revealed that the heteromorphic deutonymphal stage was skipped when suitable conditions were provided in the laboratory. The species also exhibited arrhenotoky and polyandry. The sex ratio could be recorded as 1:1.

The parasitic mite, *P. palappuramensis* sp. nov. was found to induce significant reduction in the leaf area consumed by its host insect, *O. hyla*. *Oxya hyla* infested with *P. palappuramensis* sp. nov. exhibited reduced longevity compared to uninfested grasshoppers. Different varieties of chilli plants showed variation in their predatory mite density. It was seen that the domatial characteristics of chilli leaves varied with respect to the chilli varieties and which caused variation in the predatory mite density. The chilli varieties with more number of trichomes and well developed pouch at the junction of leaf veins hosted more number of mites. The Blattisociid member, *L. (L.) moolamkudensis* sp. nov. displayed predatory activity on different stages of *B. tabaci* infesting *Capsicum annuum* Var. LV8. The various life stages of *B. tabaci* consumed by *L. (L.) moolamkudensis* sp. nov. included the egg, nymph 1 and nymph 2. The mean rate of egg consumption by *L. (L.) moolamkudensis* sp. nov. at different

prey densities like 5, 10, 15 and 20 was recorded as 3.14 ± 1.57 , 3.57 ± 1.27 , 4.71 ± 0.75 and 4.33 ± 0.57 respectively. The total consumption of egg stage was found averaged to 3.87 ± 1.29 . The mean consumption of the first nymphal stage at different prey densities like 5, 10, 15 and 20 was recorded as 3.00 ± 1.00 , 3.4 ± 0.89 , 3.00 ± 1.00 and 3.67 ± 0.57 respectively. The total consumption of nymph 1 was found averaged to 3.22 ± 0.87 . The mean consumption of second nymphal stage at different prey densities like 5, 10, 15 and 20 was recorded as 1.40 ± 0.54 , 1.40 ± 0.89 , 1.20 ± 0.83 and 1.28 ± 0.48 respectively. The total average consumption of nymph 2 was recorded as 1.31 ± 0.64 . It was seen that infestation by *B. tabaci* resulted in reduction of leaf area (50%), moisture content (8%), photosynthetic pigments like chlorophyll a (31%), chlorophyll b (12%), total chlorophyll (24%), carotenoids (48%) and protein (50%) while increased the phenolic content to about 81% when compared to that of the uninfested chilli plants. The release of the predatory mite, *L. (L.) moolamkudensis* sp. nov. on to the whitefly infested chilli plants under controlled condition caused significant reduction in the whitefly population. Release of *L. (L.) moolamkudensis* sp. nov. on infested chilli plants also resulted in a significant increase in the leaf area (168.02%), moisture content (8.96%), photosynthetic pigments like chlorophyll a (24.9%), chlorophyll b (34.68%), total chlorophyll (29%), carotenoids (59.32%) and protein content (119.78%) of chilli leaves while significantly reduced the phenolic content to 46.15% when compared to the white fly infested chilli plants, on which the predatory mite was not released.

Therefore the present study helped to record 65 species of mites associated with 24 species of insect hosts among which ten species were found new to science. Life cycle studies of a new species of mite, *H. furrowa* sp. nov. enabled to record its necromenic type of association with the weevil host, *O. longicollis*. Further, the study also helped to understand the parasitic impact of *P. palappuramensis* sp. nov. on the rice grasshopper, *O. hyla* and also helped to assess the predatory potential of *L. (L.) moolamkudensis* sp. nov. on the whitefly, *B. tabaci* infesting chilli plants.

Recommendations

Acarines have invaded almost all available habitats in the terrestrial, freshwater and marine ecosystems. They exist as either free living or ecto/endoparasites of vertebrates and invertebrates. Among the invertebrates, insects constitute the most abundant and important group of arthropods with which mites exhibit diverse kinds of associations, ranging from phoresy to parasitism and predation. The study of mites associated with insects seems highly essential in the context that many members of the class Insecta have become a potential threat to agriculture, which forms the backbone of Indian economy. Exceeding crop losses due to pest attack can cause a backlash to Indian economy and hence it is very important to bring out the most cost effective and safe control measures to suppress the pest population. A second thought over increasing and injudicious use of chemical pesticides has lead to a threshold concept in the management of arthropod pests. Biological control forms an important area in the integrated pest management programmes. The soul of a biological control programme is to understand the natural enemies of the pest existing in the natural field conditions. Biological control of pest population has become inevitable in strengthening the existing food web of an ecosystem. Since mites form an important and constant associate of several groups of insect pests, a proper understanding of the natural acarine associates of insect pests, the nature, type and extent of association on host insects etc. would become highly useful in supplementing additional data on the natural enemies, which could be judiciously exploited for formulating biocontrol programmes. The present study revealed the association of 65 species of mites belonging to 42 genera, 26 families and 3 orders with 24 species of agriculturally important insects. Further, the study also proved helpful in understanding the varied types of association existing between the insects/ life stages and mites/ varied life stages. Accordingly, different associations like phoresy, parasitism, predation and necromeny could be encountered during the study. Further, the results of the study enabled to enrich the existing knowledge on the biodiversity of India, which has already been rated as a mega diverse nation by housing around 10% of world's species. Systematic studies carried out during the

present investigation helped to contribute 10 new species to science, 55 species as new reports from India and 59 species as new associations with the so far unreported insect hosts.

Biological studies carried out during the study on a novel species of phoretic mite viz. *Histiosoma furrowa* sp. nov. which was found phoretic on the weevil pest viz. *Odoiporus longicollis* revealed a necromenic type of association of the mite with its weevil host. Since a particular type of association existing between two organisms is often found fluid over time, it is probable that phoresy can later on develop into parasitism on a progressive evolutionary pathway. This change from one type of association to another is not rapid and often exhibits an intermediate association. According to evolutionary biologists, necromeny is such a kind of association which serves as a link between phoresy and parasitism. Understanding these kinds of associations would help to augment the existing knowledge on evolutionary trend of different associations. Thus in the present study, an association which could be called more precisely as facultative necromeny was found exhibited by a novel species, *H.furrowa* sp. nov. on the pseudostem weevil, *O. longicollis*. Further, the study also helped to shed light on the life cycle parameters of the above novel species. Phoretic associations are recognised as symbiotic and hence a phoront is not expected to impede the activities of its host, though a few studies could showcase detrimental phoresy. In the present study, the impact of phoretic mite load on the body weight of three insect hosts viz. *O. longicollis*, *Oryctes rhinoceros* and *Rhynchophorus ferrugineus* was studied and found that high phoretic load would result in significant variation in the body weight of insect hosts.

The concept of employing parasitic and predatory mites for successful suppression of pest population is gaining attention and which form an integral component in IPM programs. It is equally important to study the plant characteristics that support the occurrence and distribution of natural enemies such as predatory mites on the foliage of plants. An understanding of the plant characteristics which promote the occurrence and population density of predatory mites would be helpful for recommending these plant features to be considered for incorporation in future plant breeding programmes so as to enhance the occurrence of natural enemies in the plants. In the present study, alterations in the abundance of predatory mites in relation to the domatial characteristics of host plants were studied on ten different varieties of chilli

plants. The results of the study disclosed the positive impact of trichome density and well developed pouches at the leaf axils in supporting good populations of predatory mites. Thus the study helped to recommend incorporation of such domatial characteristics like the well developed trichomes and pouchlike depression at the junction of leaf veins to be considered in the plant breeding programme of chilli plants so as to enhance the naturally occurring acarine predators. Further, the study also helped to record the predatory potential of a new species of blattisociid mite, viz. *Lasioseius (Lasioseius) moolamkudensis* sp. nov. on the polyphagous whitefly pest, *Bemisia tabaci* by conducting leaf disc experiments and also on potted chilli plants. Since it was found that *L. (L.) moolamkudensis* sp. nov. could serve as a promising predator of *B. tabaci*, the study recommends the use of *L. (L.) moolamkudensis* for the biological control of *B. tabaci*. The present study also helped to record a new species of podapolipid mite, *Podapolipus palappuramensis* sp. nov. ectoparasitic on the rice grasshopper, *Oxya hyla*. Further, it was found that parasitism by *P. palappuramensis* sp. nov. on *O. hyla* could impede its feeding activity, thereby reducing its vigour and longevity. The present finding thus helped to understand that infestation by a parasitic mite can bring out serious consequences on its host. However, the feasibility of incorporating a parasitic mite in the biocontrol programme of an insect pest still needs to be investigated under field conditions.

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Relationships between phoretic mites and their carrier, the banana pseudostem weevil *Odoiporus longicollis* Oliver (Coleoptera: Curculionidae)

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ABSTRACT

Phoresy is a type of commensalism exploited by many species of mites as a means of transportation. The present study reports the phoretic association of astigmatid and mesostigmatid mites with adults of the banana pseudostem weevil, *Odoiporus longicollis* Oliver, a major pest of banana. Weevil specimens were collected from eight localities in Kerala, South India, between June 2017 to January 2018. 91.8% of beetles carried mites: phoretic deutonymphs (hypopi) of an unknown species of *Histiostoma* (Astigmata: Histiostomatidae) and adults of *Macrocheles muscaedomesticae* (Scopoli) (Mesostigmata: Macrochelidae). When their hosts died, *Histiostoma* sp. often fed upon the cadavers of their hosts, a relationship referred here as facultative necromeny. *M. muscaedomesticae* showed preference to the ventral surface of the host weevil while *Histiostoma* sp. preferred the sternal groove and subelytral surface.

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Introduction

Exploitation of patchy habitats by mites is often accomplished by phoresy, a commensalistic relationship where one smaller animal species uses another larger, more mobile species for transport alone (e.g. O'Connor 1982; Hunter and Rosario 1988; Athias-Binche and Morand 1993; Macchioni 2007). This is true for various other animal groups also, especially among the arthropods which successfully utilize phoresy as a means of dispersal by attaching themselves to their hosts as inactive/non-feeding stages (e.g. Clausen 1976; Poinar et al. 1998). The phenomenon is defined explicitly as a dispersal or migratory strategy (Farish and Axtell 1971) that does not involve feeding, but in some cases it appears that the relationship has transformed during the course of evolution into a more permanent association (Binns 1982; O'Connor 1982; Blackwell et al. 1986; Houck and O'Connor 1991; Houck 1993; Polak 1996) and perhaps undergoing transition into true parasitism (Houck and Cohen 1995). Thus, simple phoretic relationships between mites and their carriers are often more complex than transport alone.

Our study examines the association of mites found on *Odoiporus longicollis* Oliver, the popularly called banana pseudostem weevil, which bores into the pseudostem of all species of *Musa*. The weevil, along with another species (*Cosmopolites sordidus* Germar), are important banana pests with a high potential to reduce yield. *O. longicollis* was reported to cause 10–90% of yield loss, depending up on the stage of infestation (Padmanaban and Sathiamoorthy 2001). Considering the importance of banana production in India and worldwide, the present study was undertaken to explore the acarine associates of the weevil, to explore the type of association between the mite and the weevil host, and also to analyse the attachment preferences of the mite species. Earlier studies in India recorded two species of uropodine mites with the adults of *O. longicollis* (Anitha 2000) and a species of *Uropoda* was claimed to be an ectoparasite of *O. longicollis* (Tiwar 1971), which is highly unlikely as these mites are not known to be parasitic on their hosts.

Our study found two species associated with *O. longicollis*, a species of *Histiostoma* (Astigmata: Histiostomatidae) and *Macrocheles muscaedomesticae* Scopoli (Mesostigmata:

Macrochelidae). O'Connor (2009) reported that histiostomatid mites constitute a cosmopolitan group encompassing over 500 species belonging to 58 genera. The deutonymphs of Histiostomatidae are known to be phoretic, attaching to their hosts as a non-feeding life stage. The adults and other immature life stages have highly specialized mouthparts for filtering organic materials and microorganisms from water films. These mites typically feed in this manner from the substrate in their preferred habitats.

The family Macrochelidae Vitzthum includes about 20 genera and 470 species worldwide (e.g. Ozbek and Bal 2013). Macrochelid mites are often found in decomposing matter, especially dung and carrion, where they feed on microarthropods. Numerous species are known, or suspected to be, phoretic, and usually only a mated adult female migrates in this manner (Krantz 1998). The genus *Macrocheles* is known to infest the weevil *Rhynchophorus ferrugineus* Oliver (Dilipkumar et al. 2015) and the species collected in our study, *M. muscaedomesticae*, is often reported from flies, such as *Calliphora erythrocephala* Meigen and *Musca domestica* Linnaeus (Goku and Guler 1968). It is considered an efficient predator of eggs and maggots of houseflies (Safaa et al. 2014). Despite its common association with dipterans, like *Musca domestica* and *Stomoxys calcitrans* Linnaeus, *M. muscaedomesticae* exhibits a very rare occurrence on beetles *Bubas bubalus* Oliver and *Geotrupes stercorarius* Linnaeus (Niogret et al. 2006). The present observation on the association of *Histiostoma* sp. as well as *M. muscaedomesticae* forms the first report on phoretic relationship of these species with *O. longicollis* and the study elucidates the incidence, prevalence and nature of the mite-weevil association.

Materials and methods

Collection of weevils

Live specimens of the pseudostem weevil were collected from eight localities in three districts of Kerala viz. Palakkad (10.7867° N, 76.6548°E), Thrissur (10.5276°N, 76.2144°E) and Malappuram (11.0510°N, 76.0711°E) from June 2017 to January 2018. A total of 256 weevils were collected by direct handpicking from banana pseudostems showing symptoms of weevil infestation. Infested pseudostems were cut open with a sharp knife to

expose the weevils hiding inside the pseudostems and were then hand-picked and placed in plastic jars (a big jar with multiple weevils). The jars were sealed and transported to the laboratory for subsequent microscopic examination. Laboratory rearing of the weevil and associated phoretic mites was carried out in plastic jars of 15 cm X 8 cm size on a food item comprised of pseudostem. The rearing jars were maintained at $27 \pm 3^\circ\text{C}$ and $75 \pm 3\%$ humidity and the food item was renewed frequently.

Identification and studies on the phoretic load and distribution pattern of mites on the weevil host

The weevils collected from various sampling localities were examined under a stereozoom microscope to identify the weevil species and examine their mites. Identification of weevils was based on the morphological features available in relevant literature and identification keys (Walker 2005). Data on the number and distribution pattern of mite specimens on the dorsal and ventral surfaces of different regions of the body of weevils such as the head, thorax, abdomen, upper and lower surfaces of elytra, legs, sutures and grooves, etc., were recorded. The mite specimens were carefully brushed off from the weevil's body, with a moistened fine camel hairbrush, preserved in 70% ethyl alcohol, dehydrated in 80% and 100% alcohol series and slide mounted in Hoyer's medium (Walter and Krantz 2009). The slide mounted specimens were oven dried at 45°C for 1 week. Genus and species identification of macrochelid mites were carried out with Halliday (2000) and Ozbek et al. (2015). The identification of histiostomatid mites is problematic, but our specimens key to *Histiostoma* in Hughes and Jackson (1958) and Negm and Alatawi (2011). Scanning electron micrographs were prepared by dehydrating specimens in an 80%, 90% and 100% ethanol series followed by an acetone series, subsequent sputtering with gold, and examination with a Gemini Scanning Electron Microscope (Figure 2).

The weight of the phoretic load of mites was measured by freezing the weevils for 30 min, counting the number of mites on their body, weighing the weevil, removing the mites, and then weighing the weevil again.

Statistical analysis

Statistical analysis of the data was carried out using the software IBM SPSS Statistics 20. The per cent distribution of mites on the different body parts on the dorsal and ventral surfaces of individual weevil specimens was calculated in order to know the specific site preference, if any, exhibited by mites on their weevil host. A One-way ANOVA test was carried out to assess the significant difference if any, in the distribution pattern of mites on the body surface of weevil hosts. A paired sample t-test was carried out using the data gained on mite population hosted by individual weevils to know whether there is significant difference in the weight of the weevil before and after removing mites. Correlation was used to know the nature of relationship existing between the body weight differences of the weevil host (before and after removing mites) with respect to the number of mites harboured on their body.

Laboratory rearing of the dominant species of phoretic mite, *Histiostomasp.*

The deutonymphal stages (hypopi) of the phoretic mite, *Histiostoma* sp. collected from the pseudostem weevil were transferred to plastic containers for making further observations on the life cycle of the species. Developmental studies of the mite were carried out in the laboratory at $27 \pm 2^\circ\text{C}$ and $75 \pm 3\%$ relative humidity by rearing the species in four different media such as (a) a cut piece of pseudostem, (b) paper discs overlaid

with saturated yeast (baker's yeast) solution, (c) a decapitated carcass of the weevil and (d) a carcass placed on pseudostem. The decapitated carcass was used to check the probable incidence of necromeny while the medium (d) was kept to confirm their feeding preference, either towards the carcass or to the pseudostem. Ten replicates of each of the above experiment were kept with five deutonymph per container. A cotton ball saturated with distilled water was placed under the pseudostem as well as the dead weevil specimen to prevent dehydration.

Results

The pseudostem weevil, *O. longicollis* was associated with two mite species: the deutonymphal stage of a *Histiostoma* sp. and the adult female stage of *M. muscaedomesticae*. Out of the 256 weevil specimens examined during the study, mite infestation was recorded on 235 specimens, thereby revealing a mite prevalence of 91.79% on *O. longicollis* under natural conditions.

The adults of *M. muscaedomesticae* were found moving over the abdominal ventrites of the host weevil and the number was comparatively very low, with a maximum of two per weevil. The percentage of beetle infested with *M. muscaedomesticae* was only 4%. The population density of *Histiostoma* sp. was very high, with 235 of 256 beetles infested (91.8%) at an average of 30.6 ± 2.39 mites per weevil. Its distribution showed variation with respect to body parts of the host weevil. The highest number of hypopi of *Histiostoma* sp. was found on the groove anterior to the mesosternum of the host weevil where the rate of infestation was 45.34%. The subelytral surface of the weevil was the second preferred site where 25.23% of deutonymphs were found harbouring (Figure 1, Table 1). The one-way ANOVA test confirmed that *Histiostoma* sp. preferred attachment to certain body regions of the host weevil ($F = 42.6$; $p < .0001$; $df = 8$).

Incidence of phoretic mites was found to result in a gain of body weight by the weevil hosts. The mean body weight of the weevil hosts harboured by the mites was 125.27 ± 3.99 mg and that of the weevil without phoretic mites was 121.35 ± 4.02 mg, thereby registering a mean weight gain of 3.92 mg. Results of the t-test (using 25 sample specimens) carried out using the above data indicated a significant weight gain by the host weevil owing to the load of phoretic mites ($t = 9.809$, $p\text{-value} < 0.001$). A positive correlation was found between the body weight difference of the weevils (before and after removing mites) and the number of phoretic mites carried by them ($R^2 = 0.9928$) (Figure 3).

The deutonymphal stages of *Histiostoma* sp. were successfully reared in the laboratory on different media such as the cut piece of pseudostem, paper discs saturated with yeast solution and decapitated carcass of the weevil. In all the above media, the deutonymphs successfully moulted into the tritonymphal stage and continued development to the adult stage. Tritonymphs reared with the decapitated beetle cadaver fed on the carcass until the succulent portions were completely depleted.

The phenomenon of facultative necromeny was observed not only in the tritonymphal stages but also among the larvae and adults of *Histiostoma* sp. The deutonymph of the mites were found to wait until the weevil carcass became succulent and moult successfully into the tritonymph (Figure 2(c)). The moulting took place in 2–3 days in case of the deutonymph on the dead weevil. In the other two cases, where the deutonymph was placed in the yeast solution and pseudostem, it took 5–6 days to moult into tritonymph. All the successive stages were found to feed on the carcass of the decapitated weevil. When the mites were provided with the carcass placed on the pseudostem, about half of them dislodged on to the pseudostem and resumed development.

Discussion

Phoresy is a form of ectosymbiosis or commensalism (Hodgkin et al. 2010) and in most cases is a passive type of dispersal that

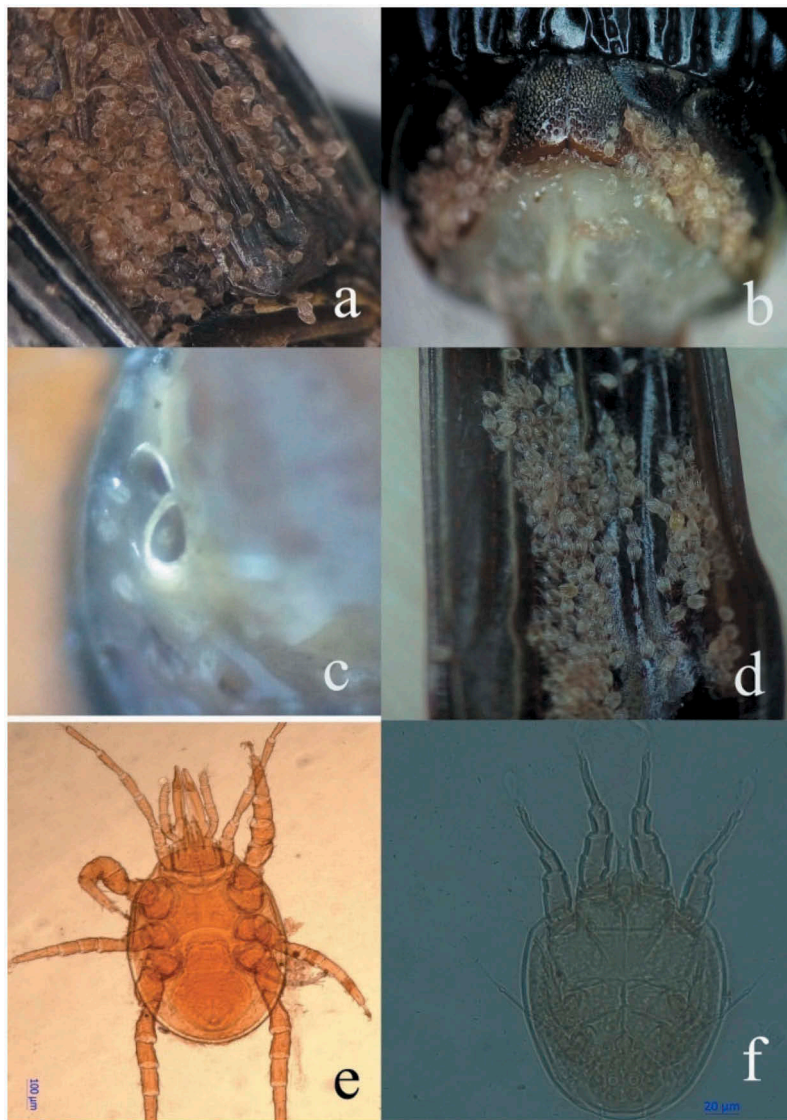


Figure 1. Phoretic hypopi of *Histiostoma* sp. on (a) hindwings, (b) anterior mesosternum, (c) tritonymph growing on decaying body part, (d) subelytra, (e) slide mounted *Macrocheles muscaedomesticae* and (f) slide mounted *Histiostoma* sp.

does not affect the host. However, sometimes the phoronts may present a physical burden on their hosts (Houck and Cohen 1995).

In our study, the two phoretic species were adults of *M. muscaedomesticae* and deutonymphs of a *Histiostoma* sp. The former species was present in low numbers in purely phoretic relationship, with no feeding on adult insects as found by Safaa et al. (2014) and Polak (1996). The latter species was, in contrast, present at a high prevalence and intensity.

The phoretic deutonymphs of *Histiostoma* sp., unlike the adult phoronts of *M. muscaedomesticae*, were found to exhibit specific site preference and distribution pattern on the body of their weevil host. The number of phoretic hypopi was very low on the abdomen and hind wings of the host weevil and hence these sites could be considered as less preferred, being directly exposed to the influence of external factors during flight, abrasion within the pseudostem, or the hind wings may be unsuitable for attachment. The distribution of phoronts on less preferred sites might be due to the overcrowding at the preferred regions. The preferred sites like the mesosternal groove and subelytral surface represent the most concealed spaces and therefore represent the least exposed areas. The beetle is not a strong flier, hence, these two sites would provide maximum protection while the host bores inside the pseudostem. A similar site preference was found in phoretic mites on *Rhynchophorus ferrugineus* Oliver, where the phoronts preferred the subelytral surface

since it offers maximum protection to the mite as the weevil walks on the rough date palm tree trunk (Al-Deeb et al. 2011).

Our study found that the load of *Histiostoma* sp. was measurable and represented a mean increase of about 3% in the weight of the weevil. Most phoretic relationships are assumed to have little or no impact on the host, although sometimes they may affect flight (Kinn 1971). High phoretic loads by the parasitic mite *Acarophenax lacunatus* Cross & Krantz was reported to impair the take-off ability of *Rhyzopertha dominica* Fabricius adults (Rocha et al. 2009). In this case, we do not know if the small increase in weight is biologically significant. Considering that the beetle spends much of its life within the host plant, we do not expect the mites to have much impact on their host.

We assume that the typical life cycle of the *Histiostoma* sp. occurs within the banana pseudostem, most likely associated with the decaying tissue which is induced by the beetle's feeding. Deutonymphs attach to the beetle, where they remain until certain cues unknown to us trigger detachment and moulting to the tritonymphal stage. These cues may be as simple as the presence of suitable food, as deutonymphs moulted to the tritonymphal stage in the presence of paper discs saturated with yeast solution. Because mites continued development on all substrates, including beetle cadavers, the observed necromenic habit was facultative unlike the report by Wirth (2009) where the smaller phoretic animal attaches until its host dies, then feeds on its cadaver. In his study,

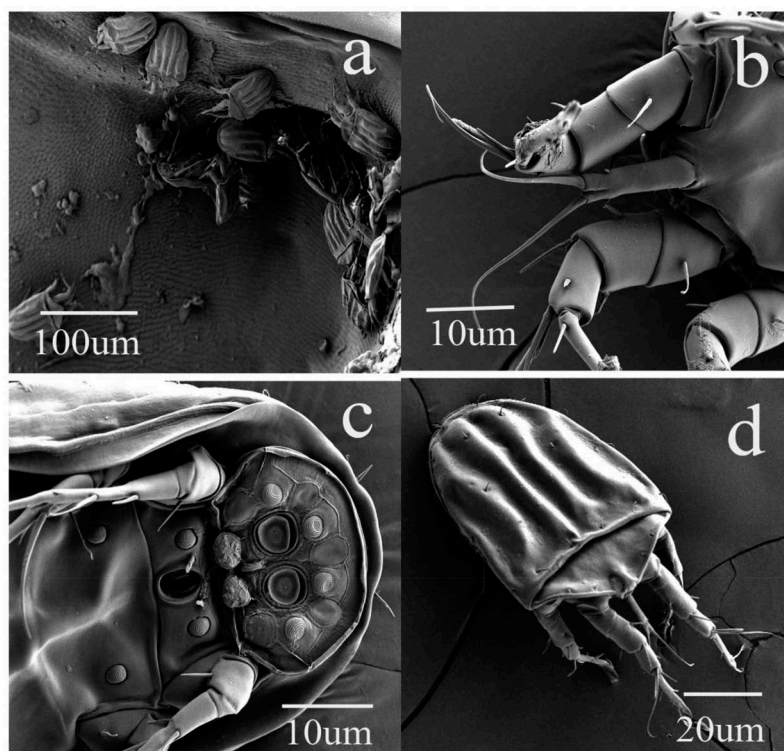


Figure 2. SEM images of hypopi showing (a) *Histiostoma* sp. on the elytra, (b) Region of gnathosoma, (c) anal suckers and (d) the dorsal view of *Histiostoma* sp.

Table 1. Percentage distribution of hypopi of *Histiostoma* sp. on the body of the host weevil, *Odoiporus longicollis*.

Body part of insect	Percentage of infestation	Range of number of mites
Prosternum	12.6%	0–36
Meso-ventrite	10.38%	0–35
Meta-ventrite	2.76%	0–29
Abdominal ventrite	0.54%	0–4
Sub elytral surface	25.23%	0–317
Hind wings	2.59%	0–96
Elytra	0.59%	0–10
Groove anterior to mesosternum	45.34%	0–114

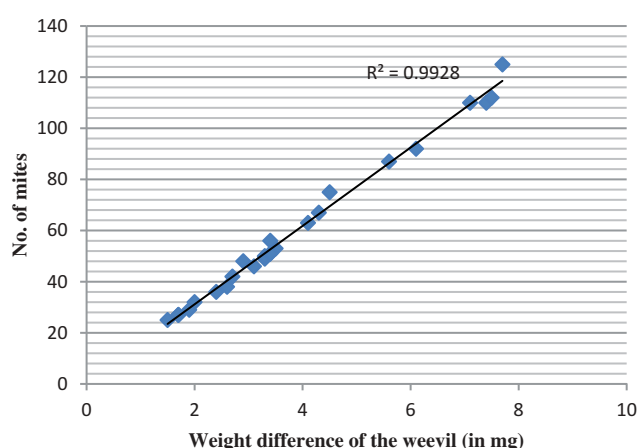


Figure 3. Correlation between body weight of the weevil host and the number of phoretic hypopi of *Histiostoma* sp.

deutonymphs of *Histiostoma* fed only on dead earwig nymphs, then attached to the surviving later stage nymphs in the earwig's brood.

This conclusion is further supported by our observations that mites moved from their carrier to pseudostem, and they therefore were not waiting for the death of their host, as is

required for the relationship of obligate necromeny (Kiontke and Sudhaus 2006).

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Disclosure statement

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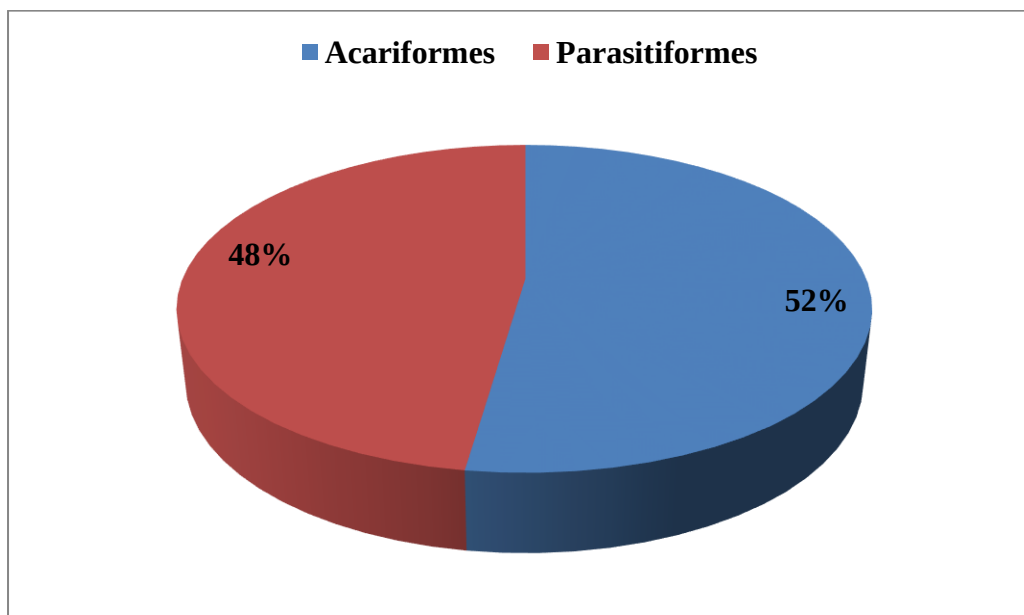


Figure. 1.8. Percentage composition of the two superorders of the subclass Acari recovered during the study

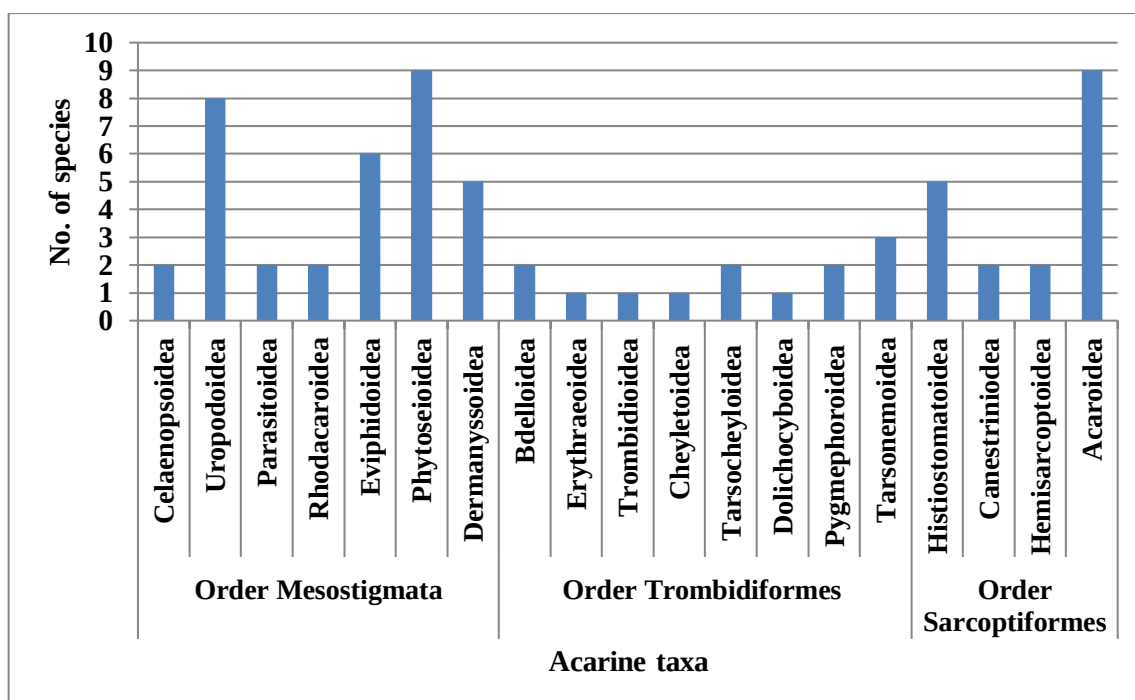


Figure. 1.9. Number of species recovered under the various superfamilies of the three orders of subclass Acari

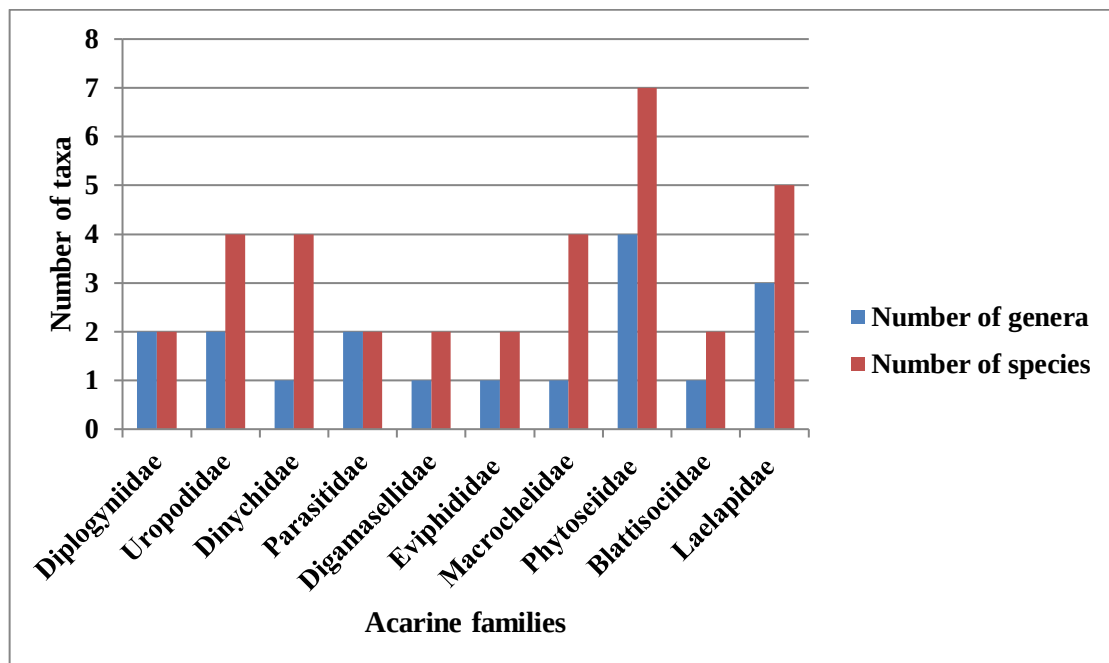


Figure. 1.10. Number of mite taxa recovered under different families of order Mesostigmata

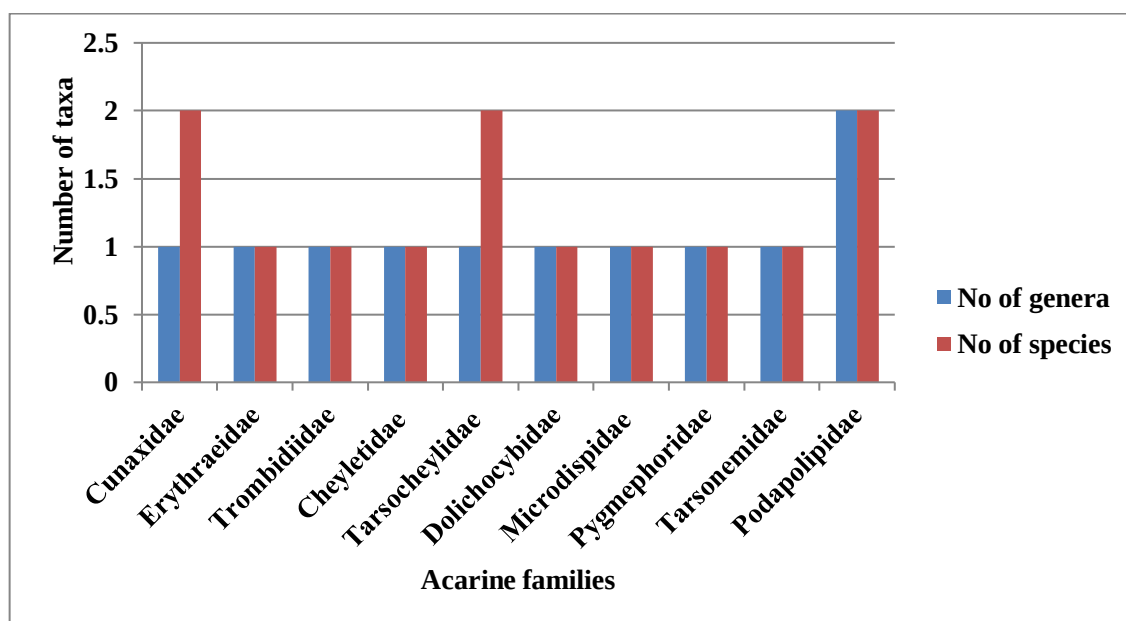


Figure. 1.11. Number of mite taxa recovered under different families of order Trombidiformes

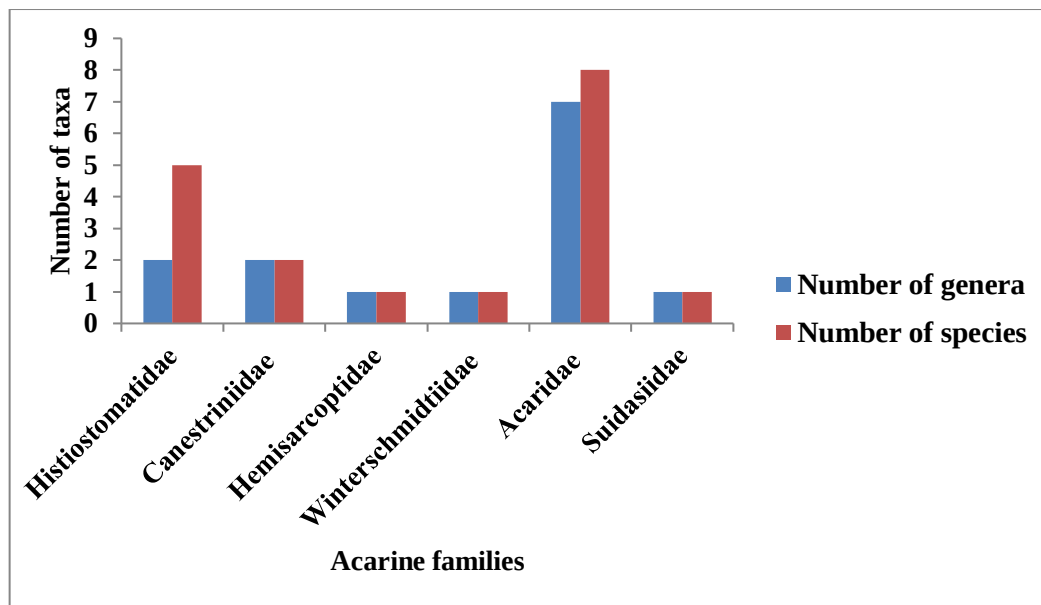


Figure. 1.12. Number of mite taxa recovered under different families of order Sarcoptiformes

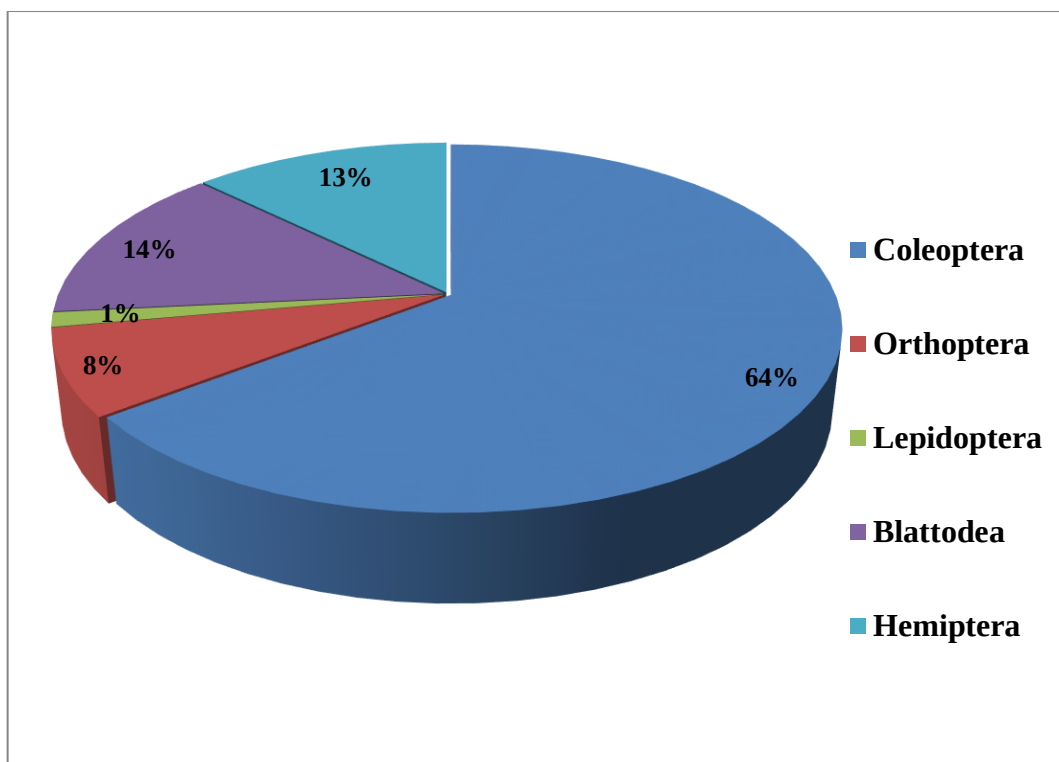


Figure. 1. 23. Species composition of mites (%) recovered from the different orders of insect hosts

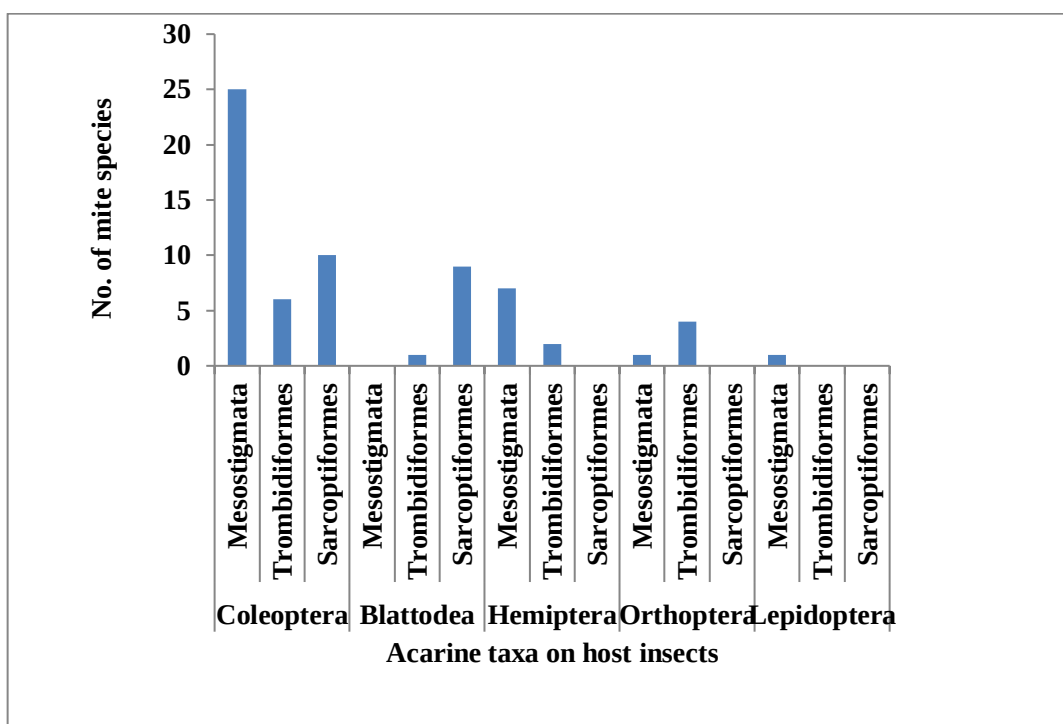


Figure. 1.24. Number of species recovered under various acarine orders associated with insect hosts

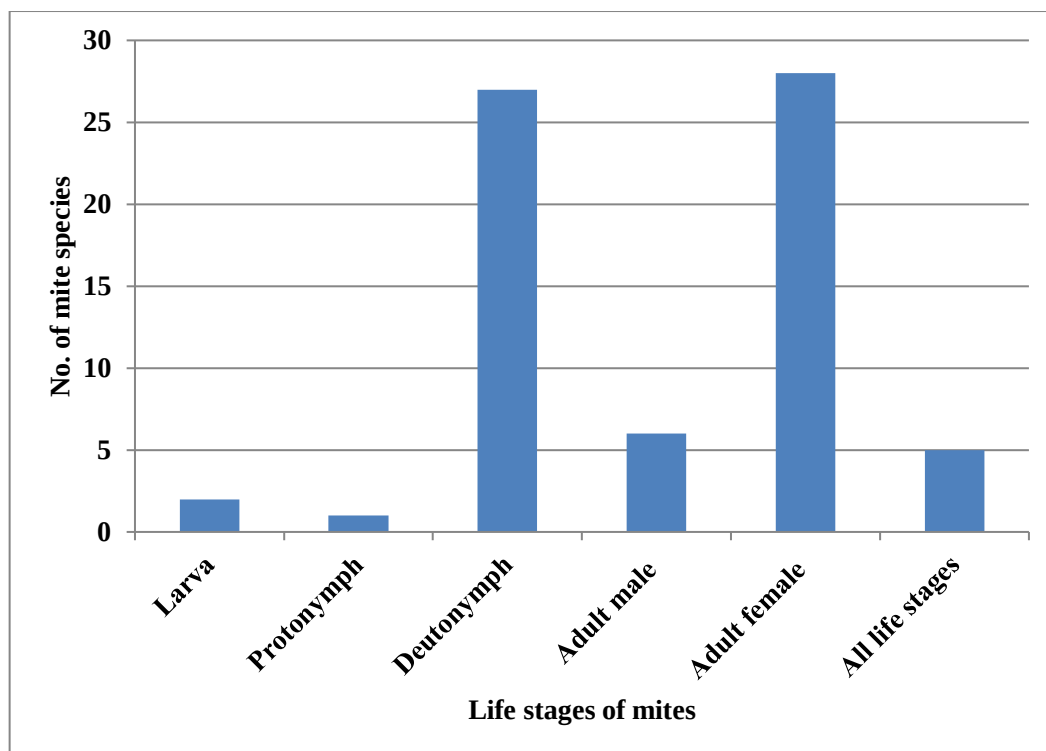


Figure. 1.25. Relative abundance of the varied life stages of mites

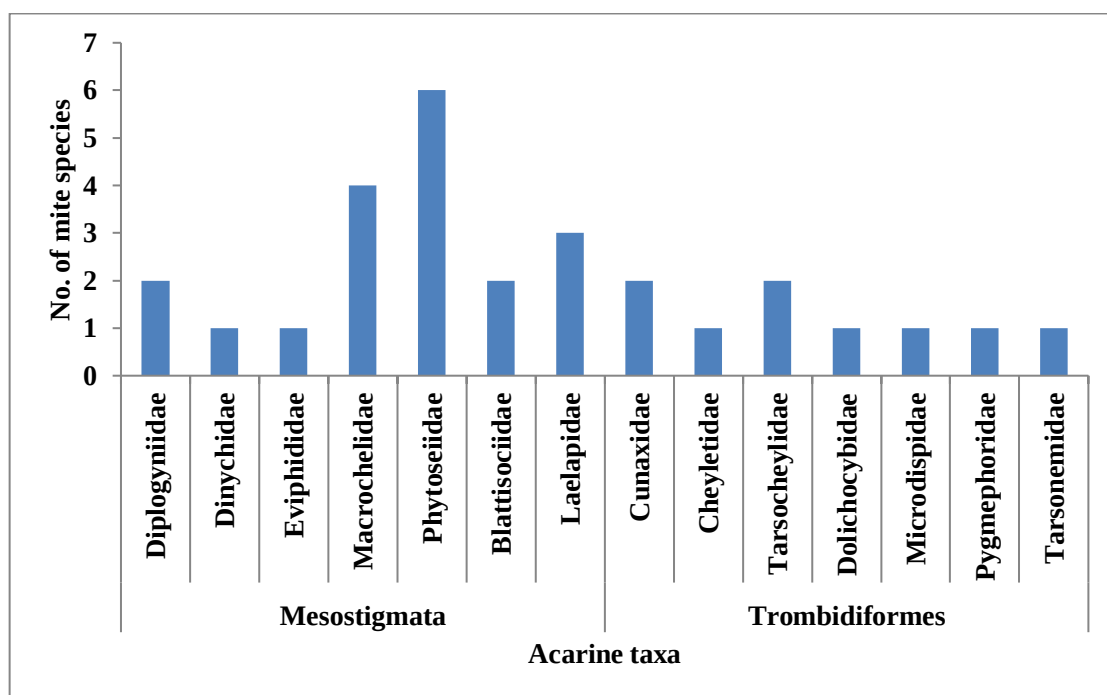


Figure. 1.26. Relative abundance of the acarine families which established insect association through their adult female stage

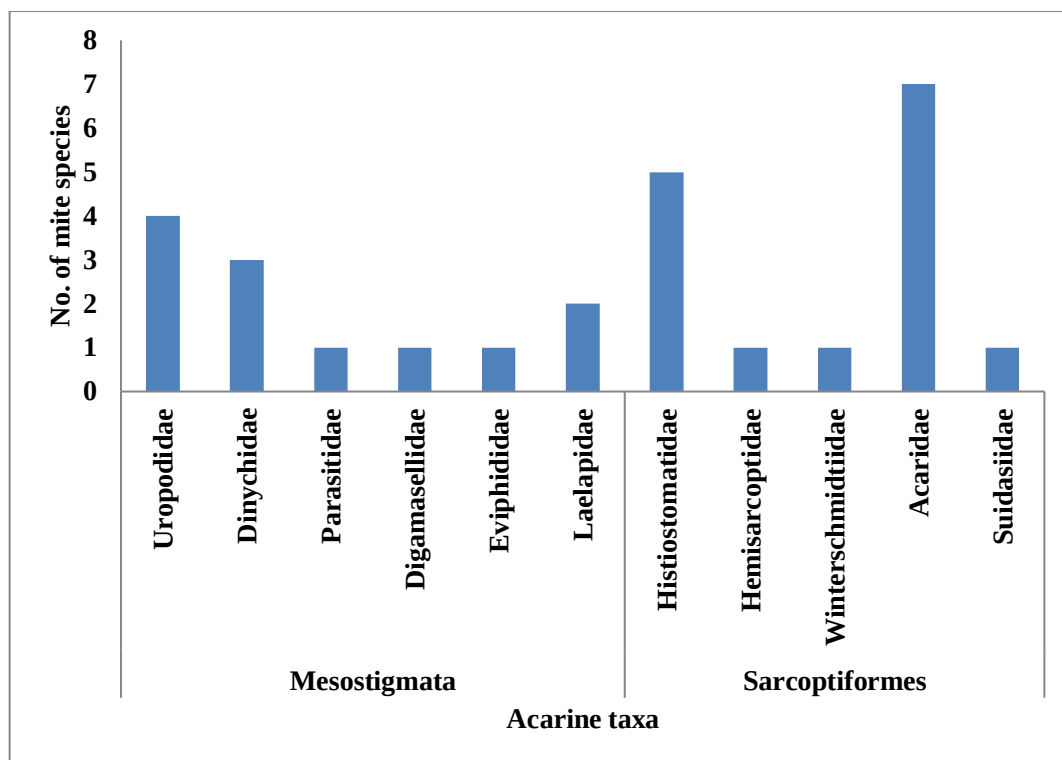


Figure. 1.27. Relative abundance of different families of mites which established insect association through their deutonymphal stage

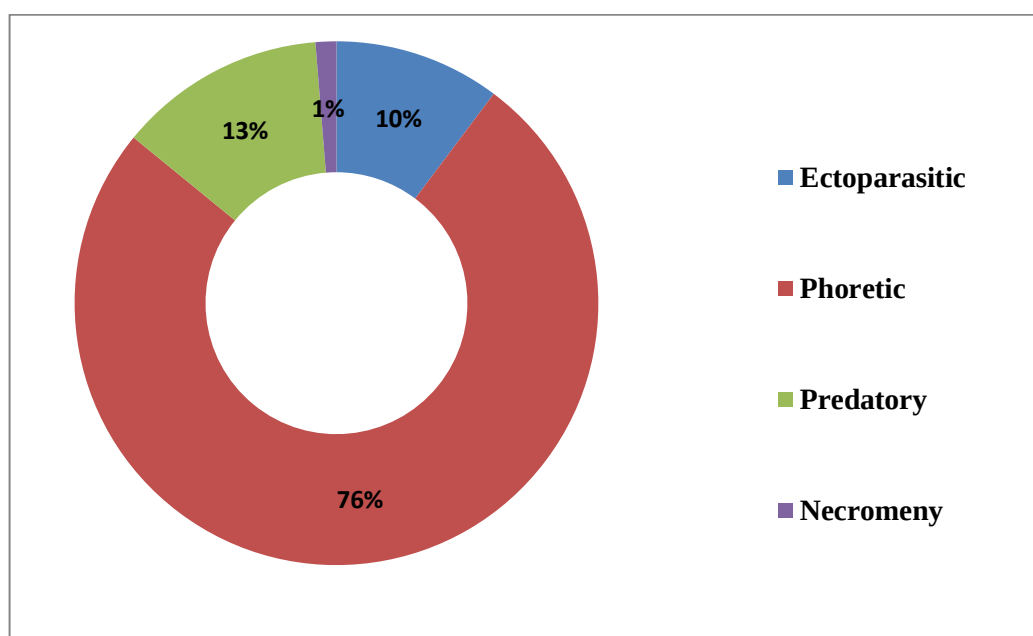


Figure.1. 28. Relative incidence of the varied types of insect-mite association

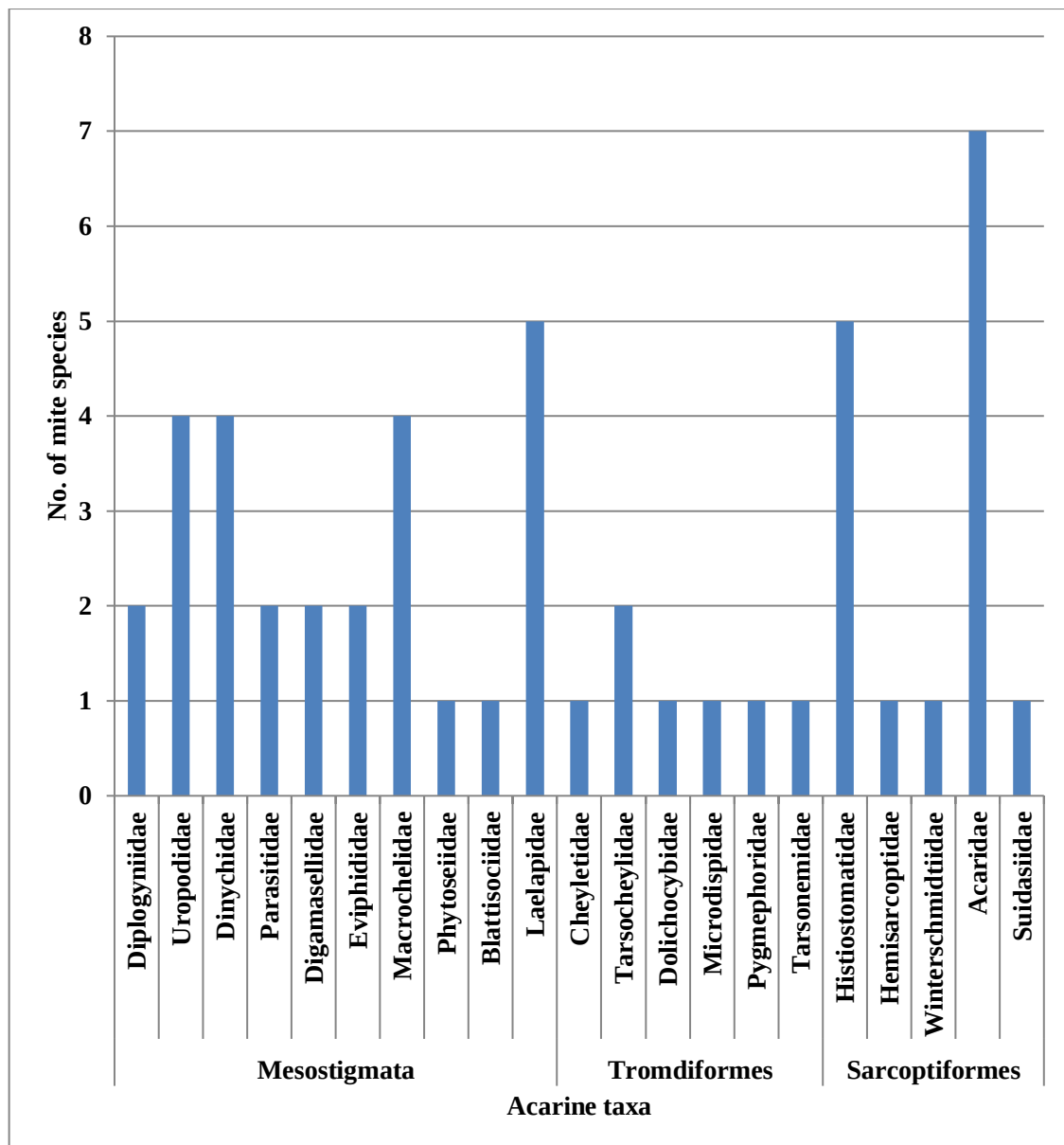


Figure. 1.29. Relative abundance of the different species under various families of acarine orders which established phoretic association with insect hosts

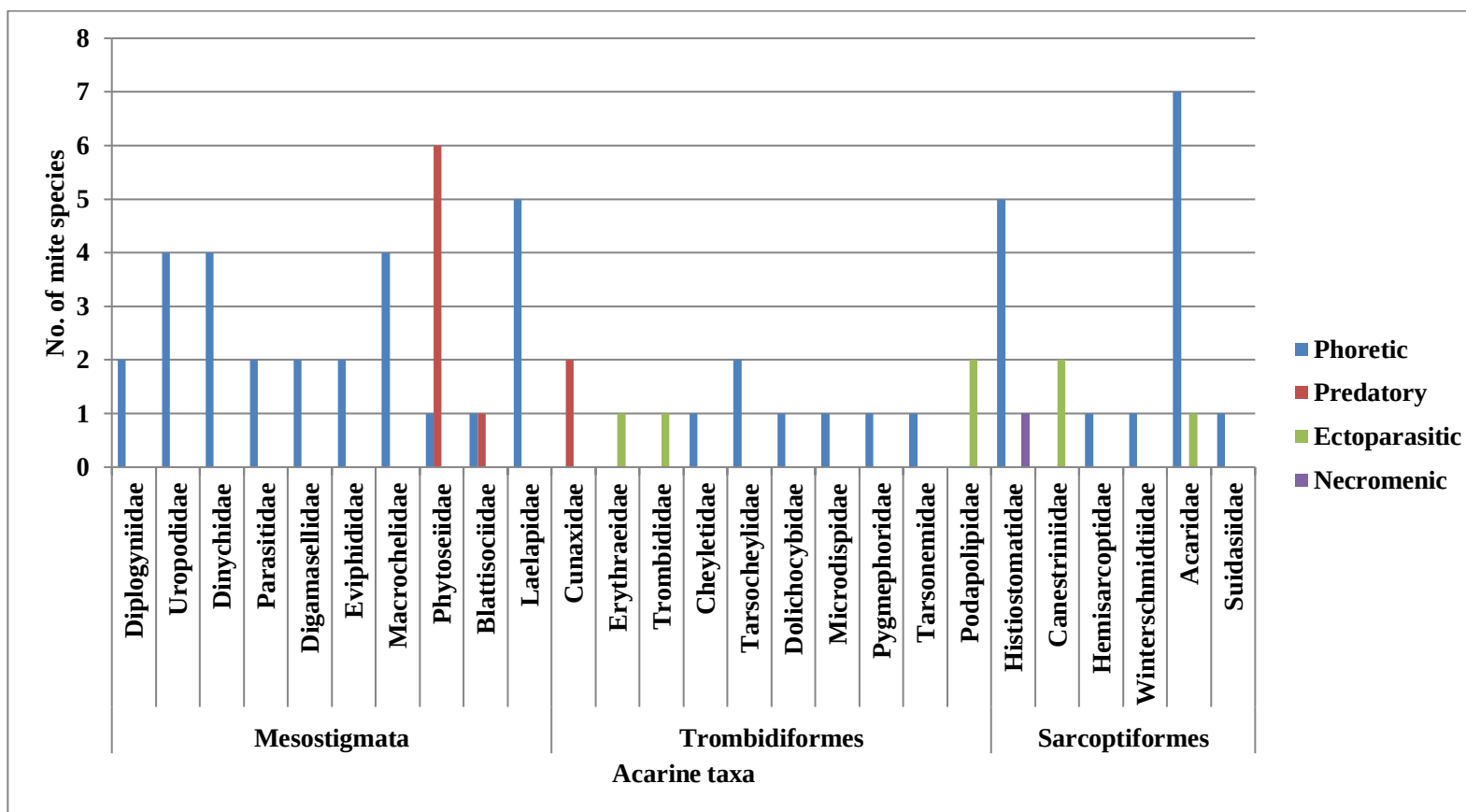


Figure. 1.30. Number of mite species under different families of acarine orders which showed diverse kinds of association with insect hosts

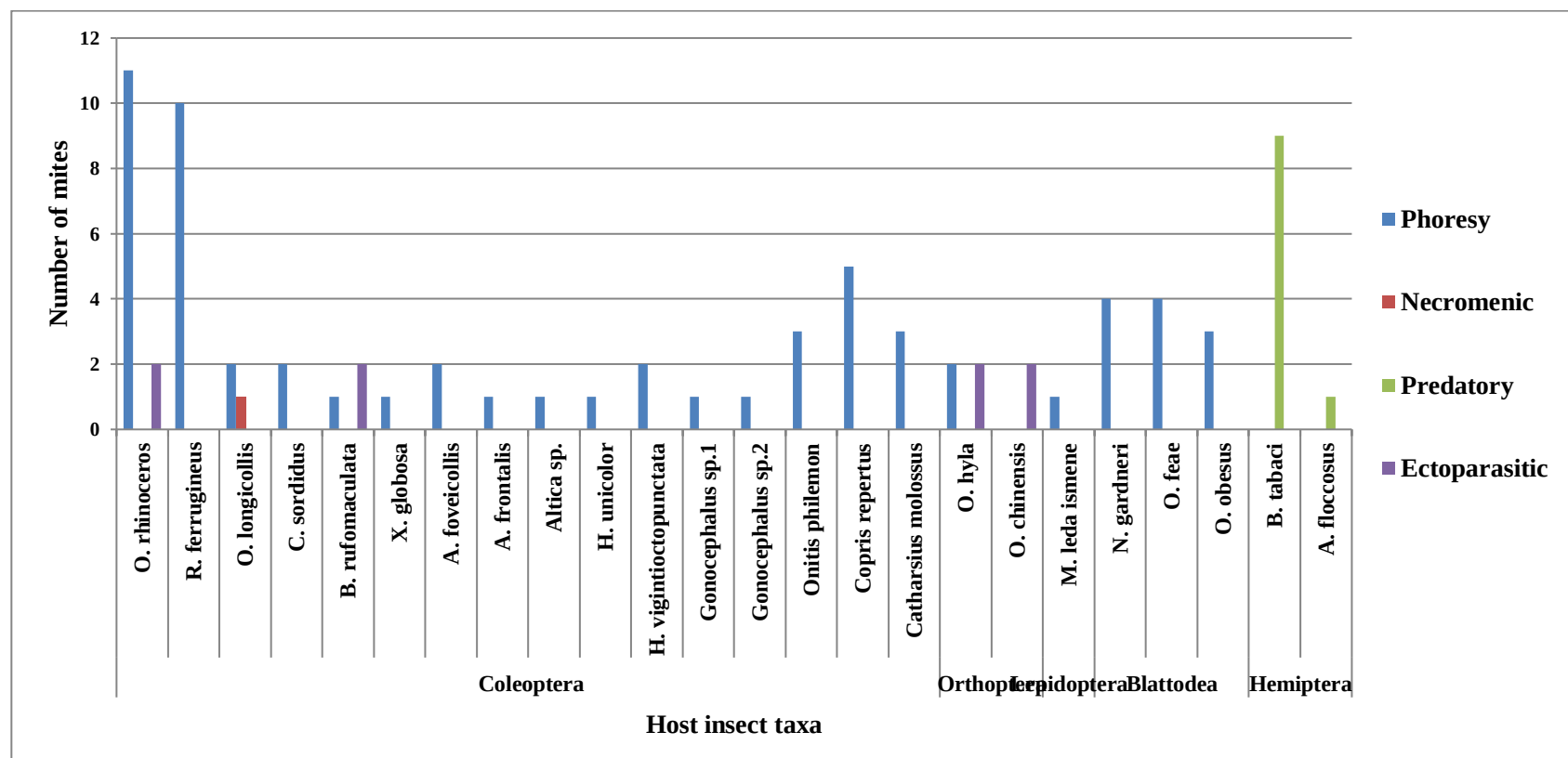


Figure. 1.31. Relative abundance of mite taxa showing diverse types of associations with insect hosts

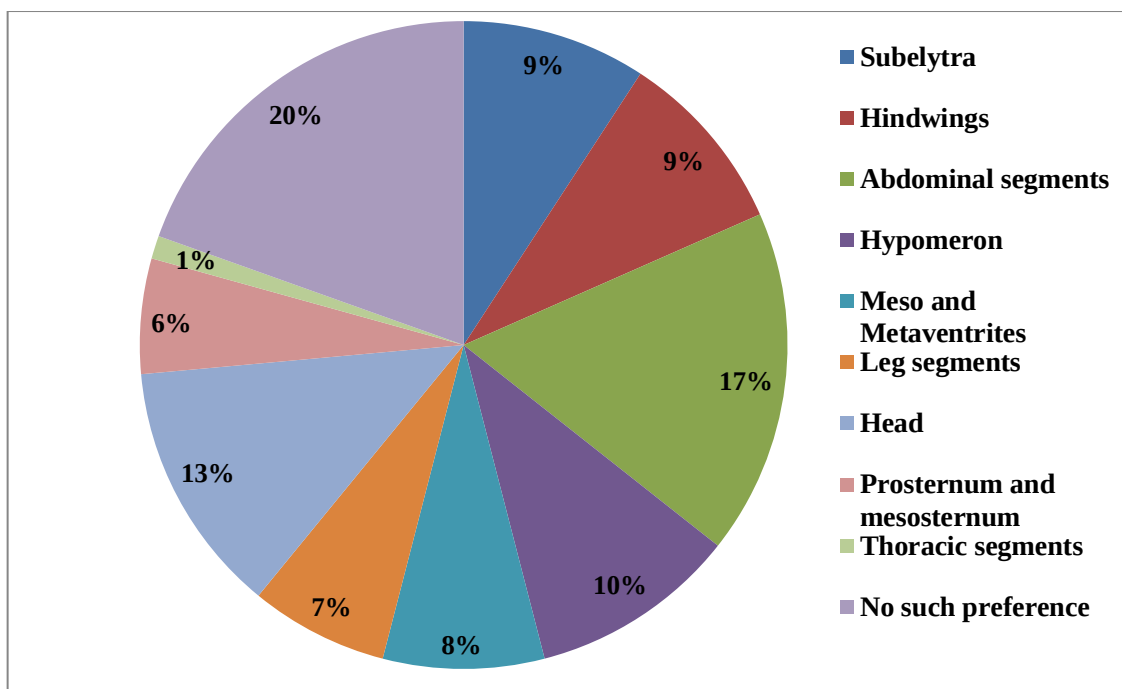


Figure. 1.32. Distribution of mites (%) on different body parts of insect hosts

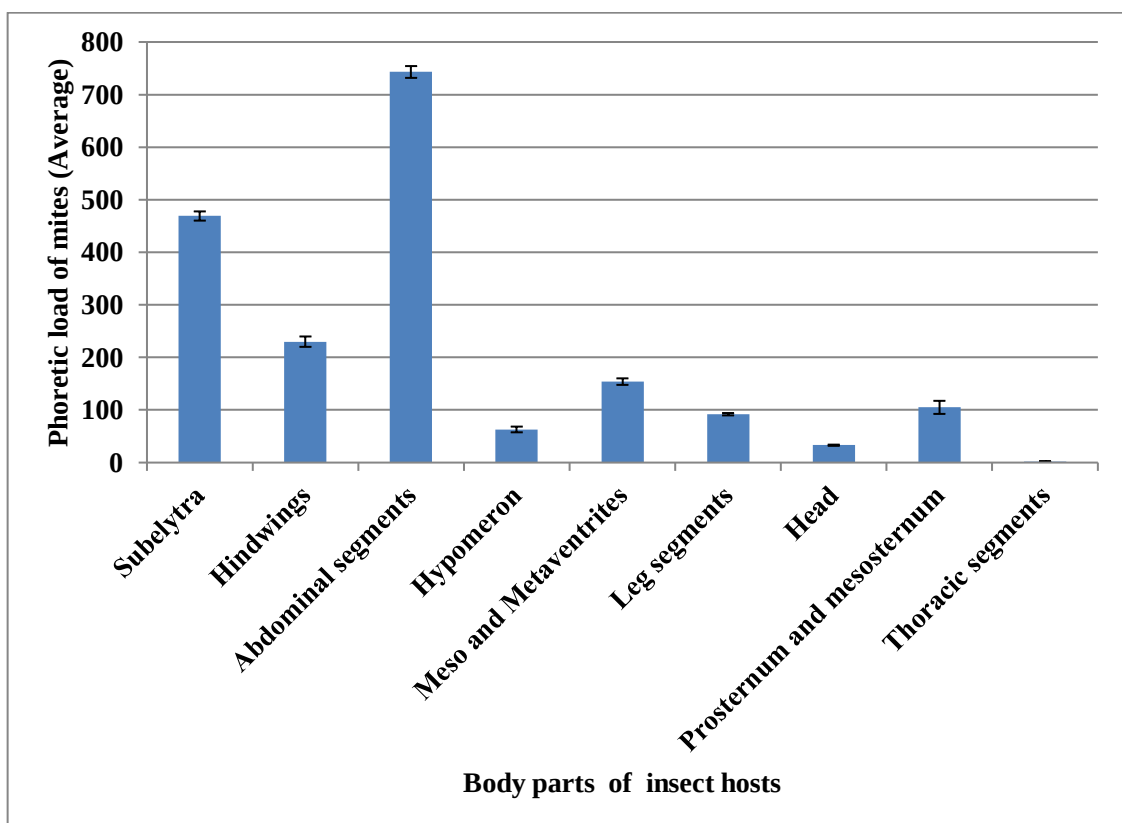


Figure.1. 33. Average number of mites on different body parts of insect hosts

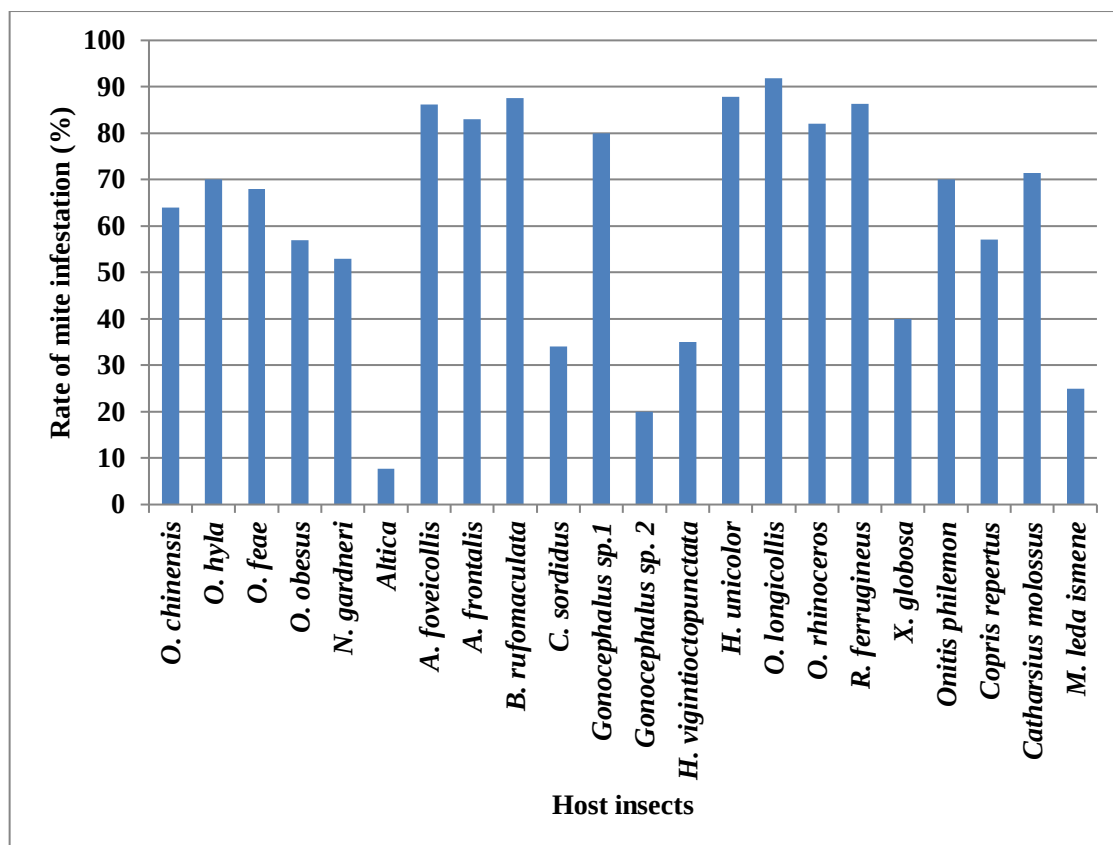


Figure. 1.34. Rate of mite infestation (%) on adult stages of insect hosts

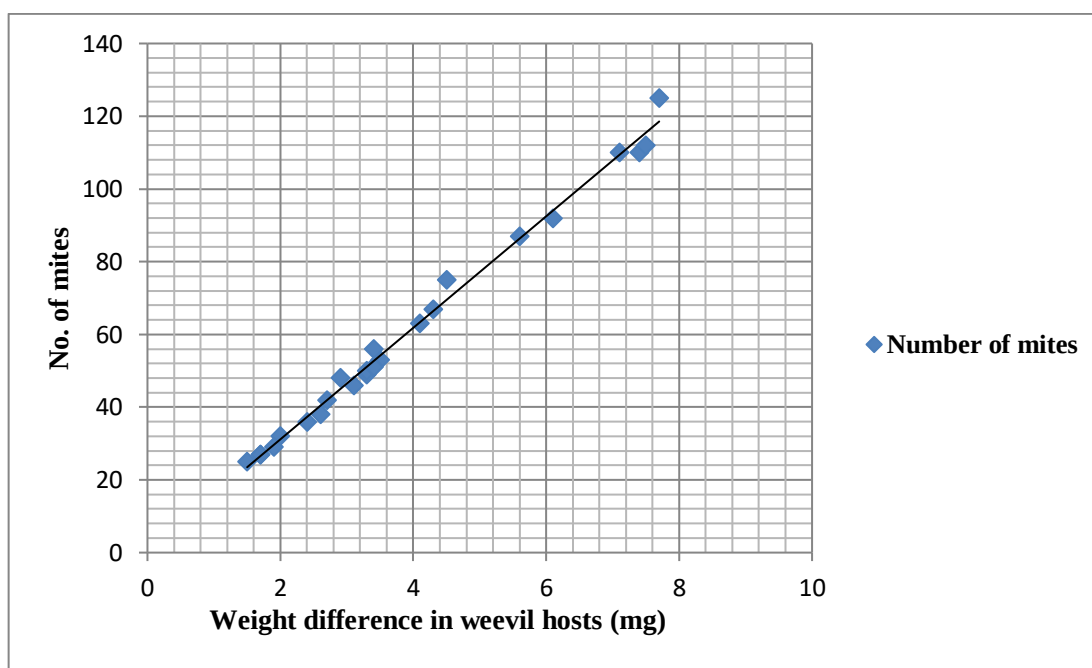


Figure. 1.35. Correlation between body weight of *Odoiporus longicollis* and the number of phoretic mites.

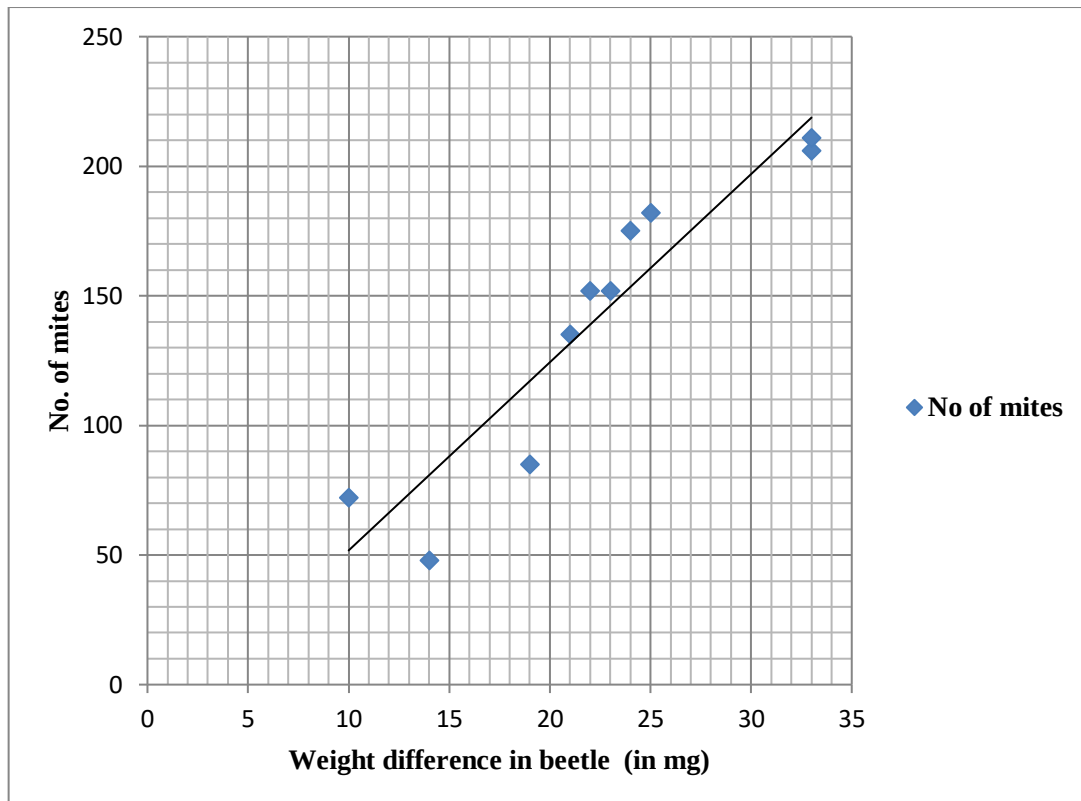


Figure. 1.36. Correlation between body weight of *Oryctes rhinoceros* and the number of phoretic mites.

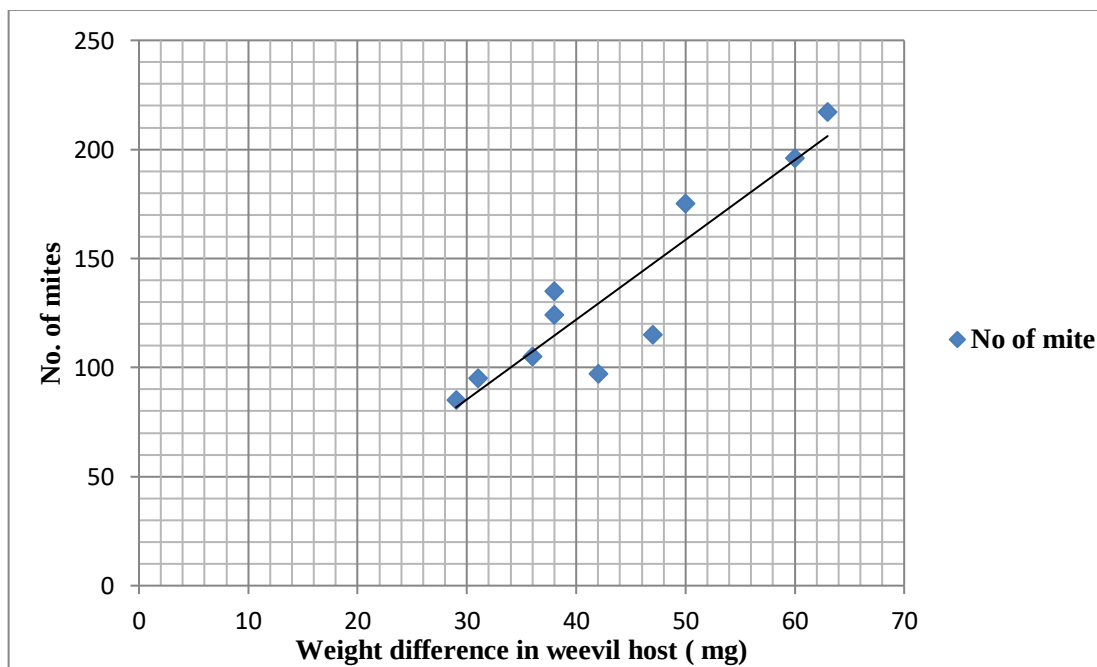


Figure. 1.37. Correlation between body weight of *Rhynchophorus ferrugineus* and the number of phoretic mite

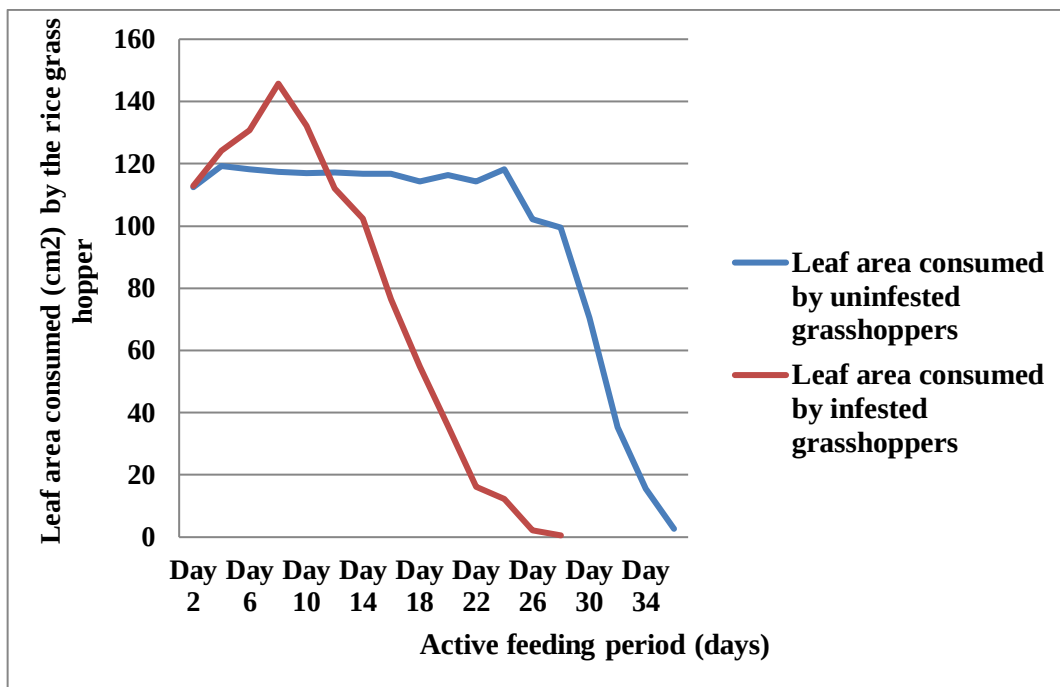


Figure. 2.7. Mean leaf area (in cm²) consumed by the rice grass hopper in experimental and control sets of paddy plants

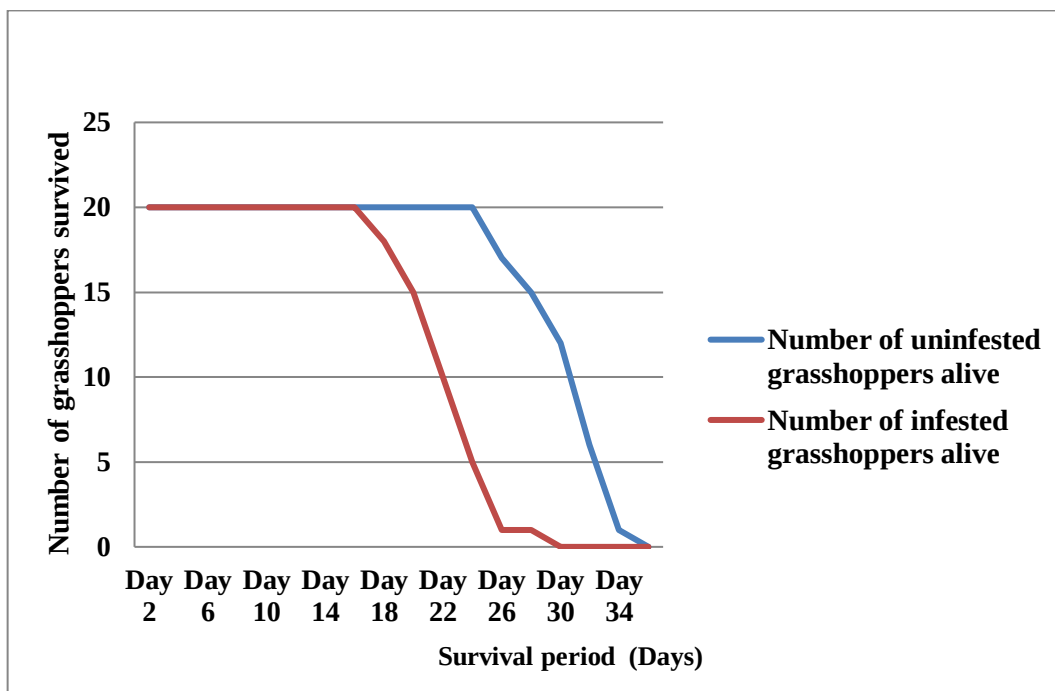


Figure. 2.8. Number of grasshoppers survived in the experimental (mite infested) and control (mite free) sets on different days

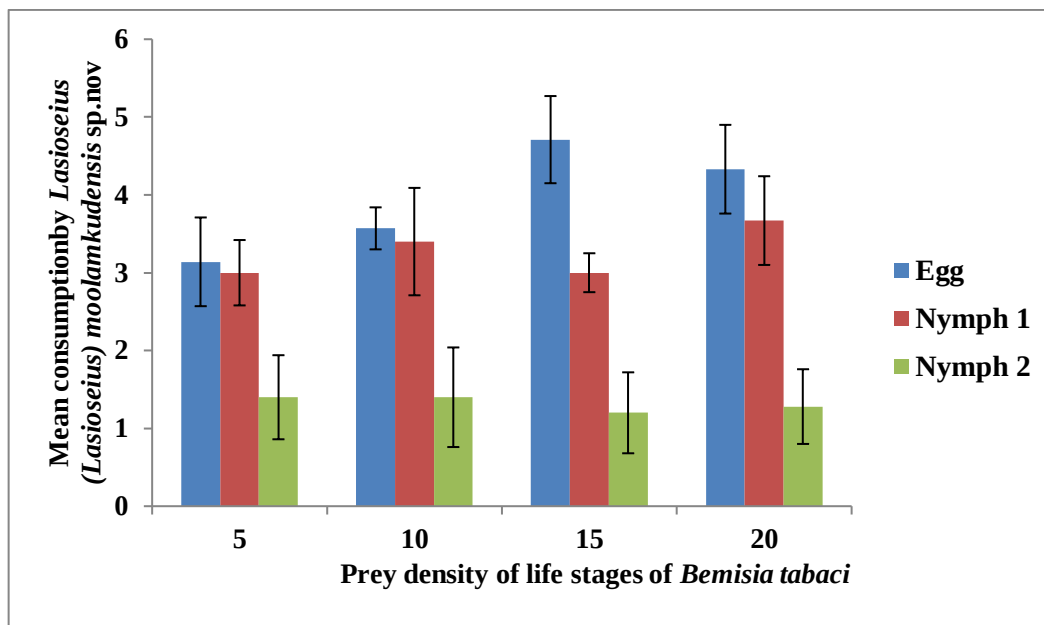


Figure. 2.11. Mean consumption by *Lasioseius (Lasioseius) moolamkudensis* sp. nov. on various life stages of *Bemisia tabaci* at four different prey densities

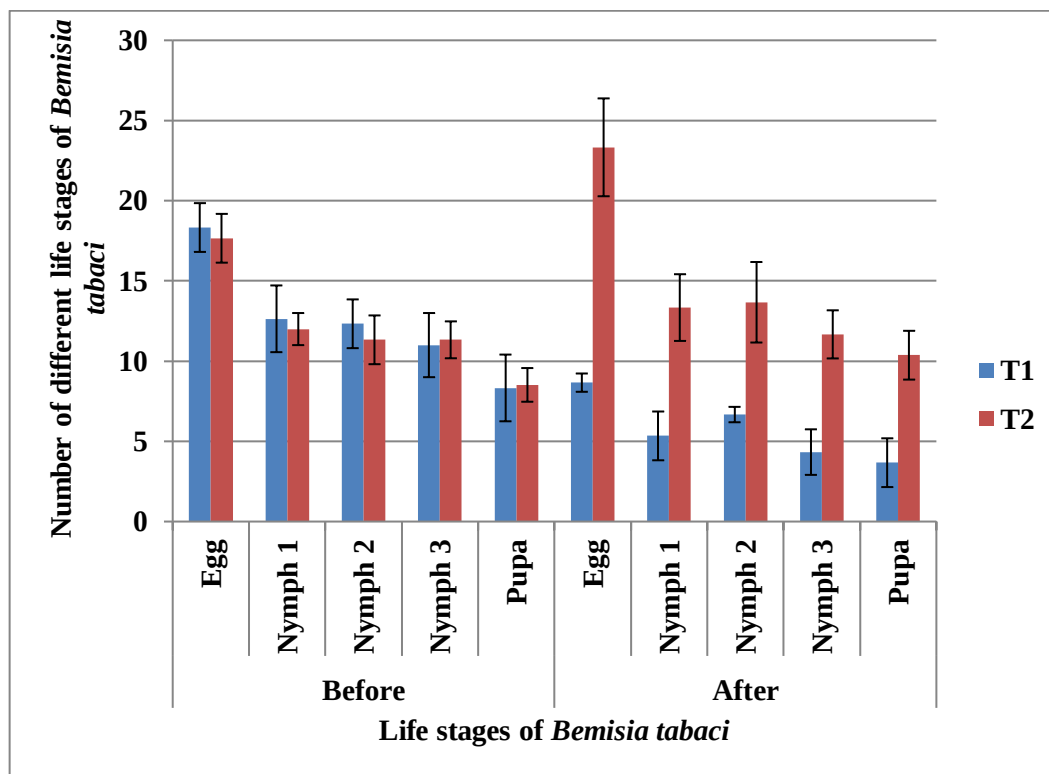


Figure. 2.12. Number of different life stages of *Bemisia tabaci* before and after release of *Lasioseius (Lasioseius) moolamkudensis* sp. nov.

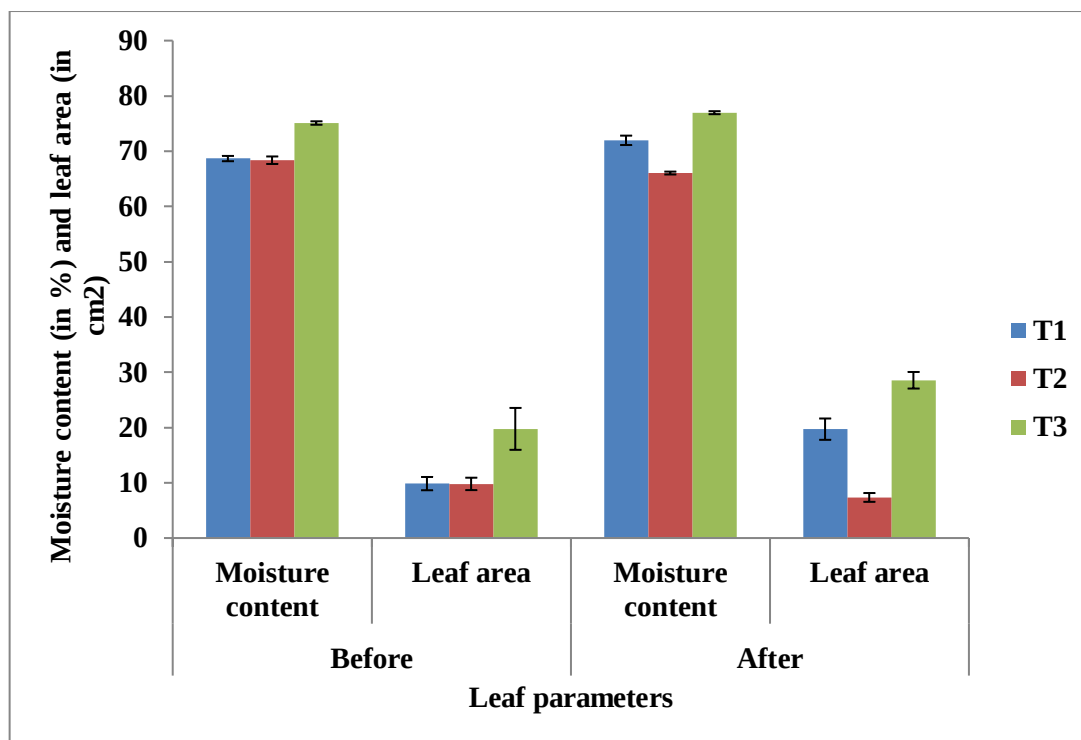


Figure. 2.13. Moisture content and leaf area of paddy plants in three experimental sets before and after release of *Lasioseius* (*Lasioseius*) *moolamkudensis* sp. nov.

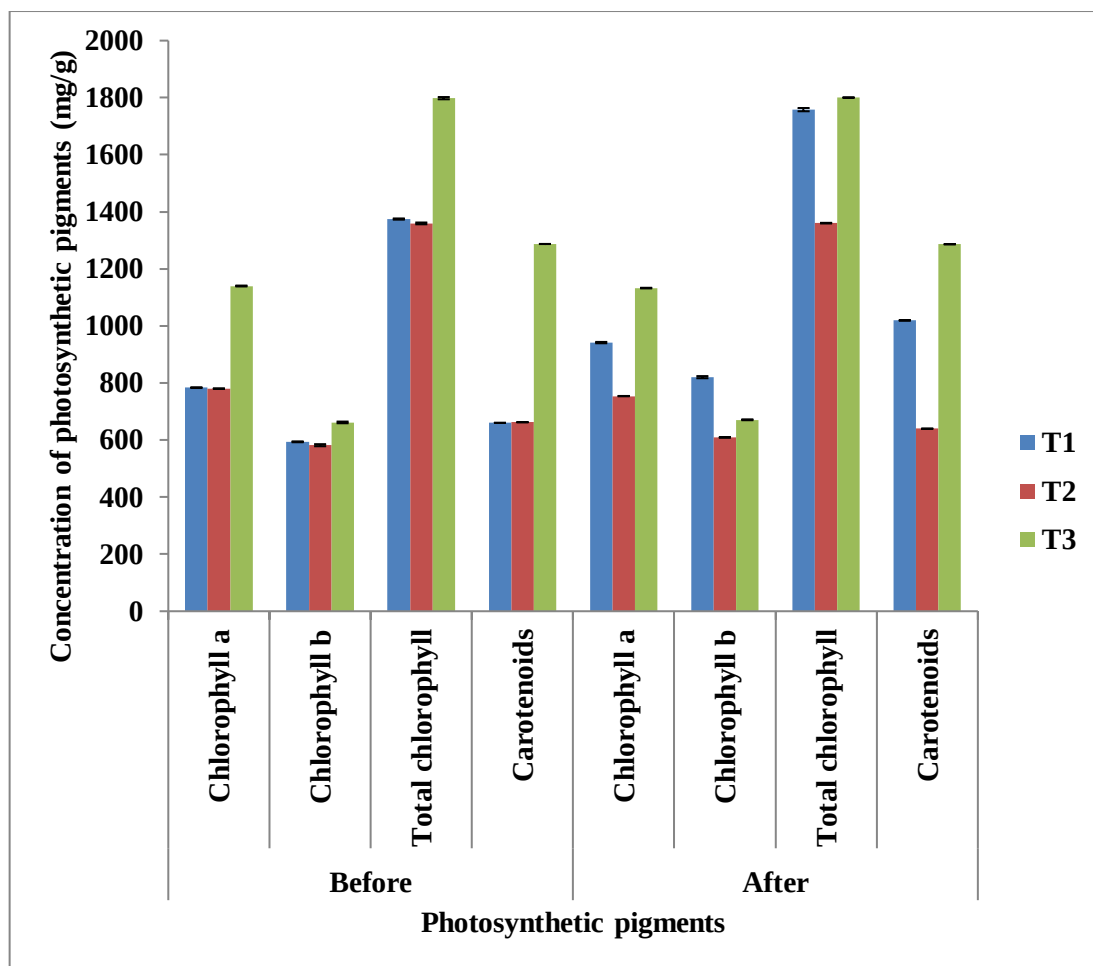


Fig. 2.14. Concentration of photosynthetic pigments of paddy leaves in the three experimental sets before and after release of *Lasioseius (Lasioseius) moolamkudensis* sp. nov.

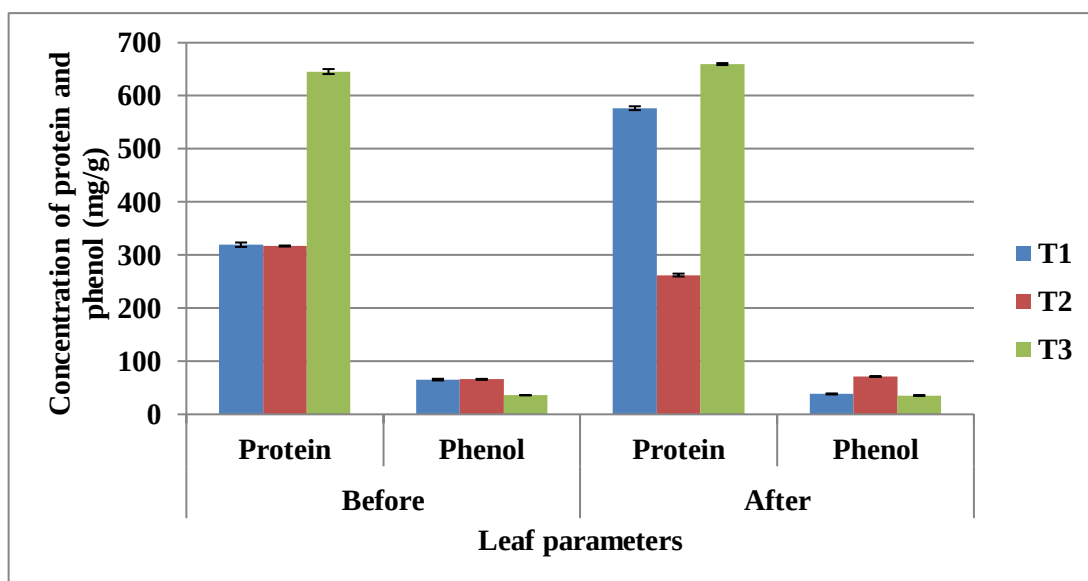


Figure. 2.15. Concentration of protein and phenol in the three experimental sets before and after release of *Lasioseius (Lasioseius) moolamkudensis* sp. nov.

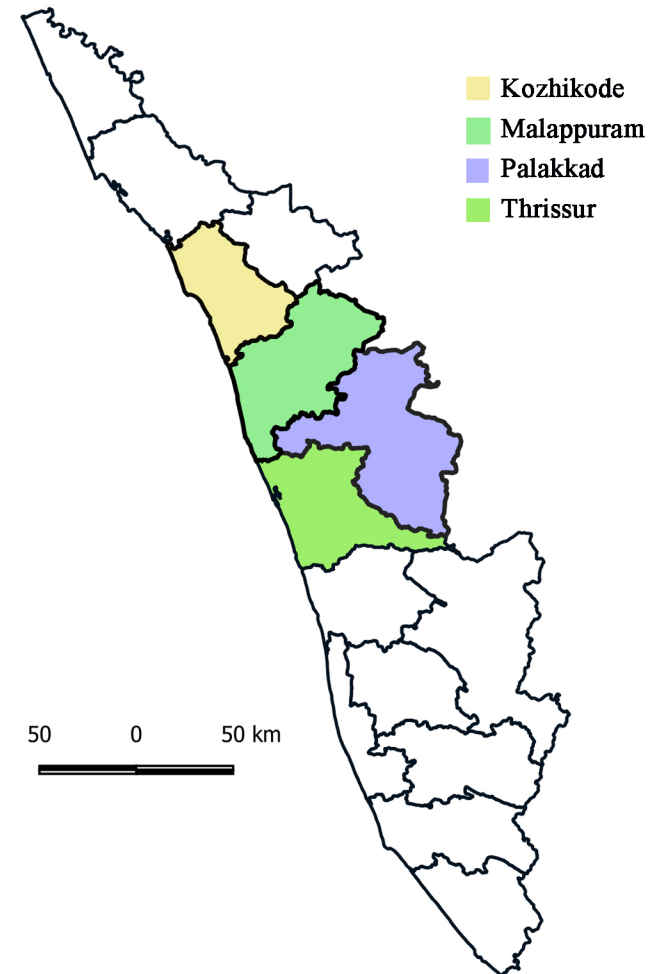
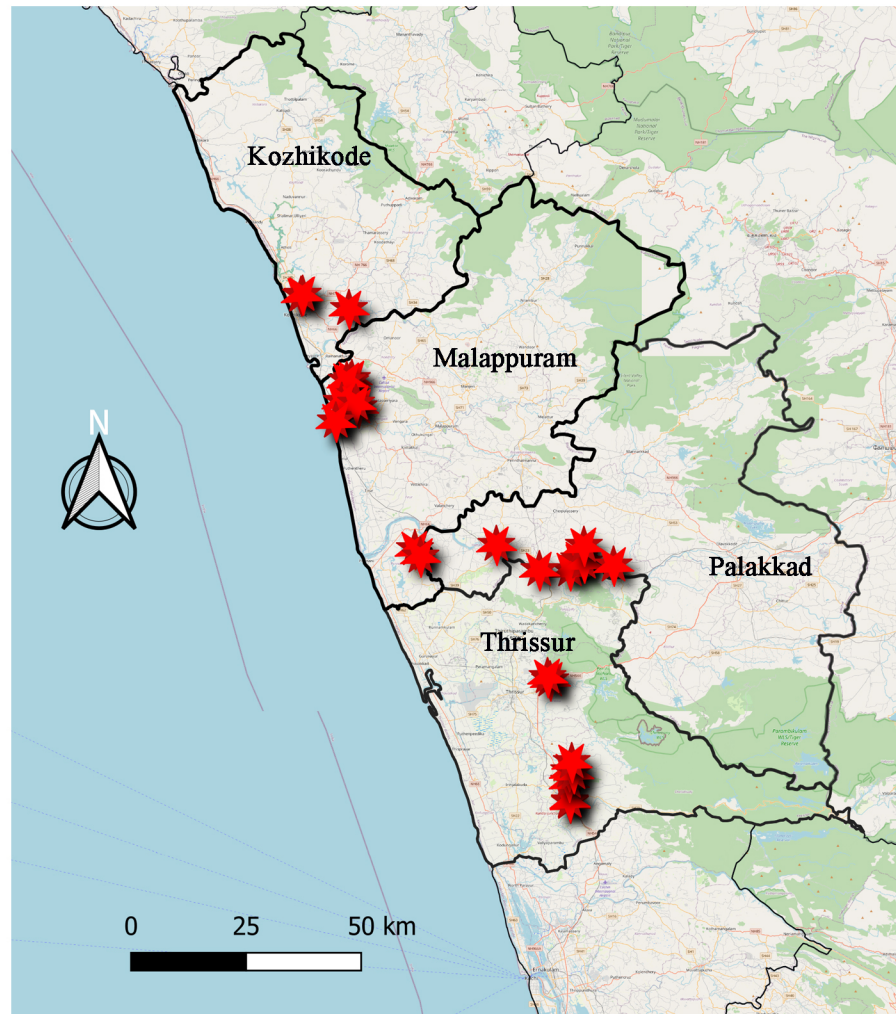
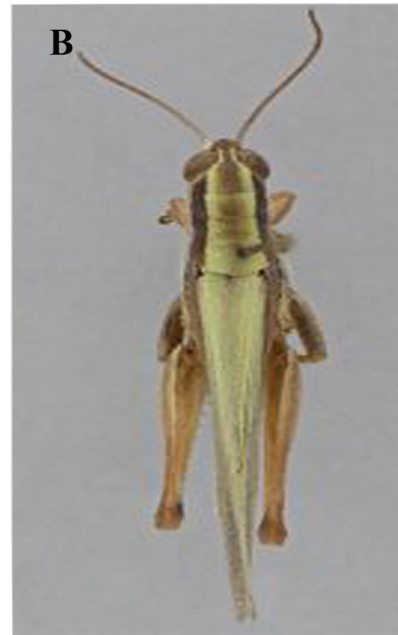
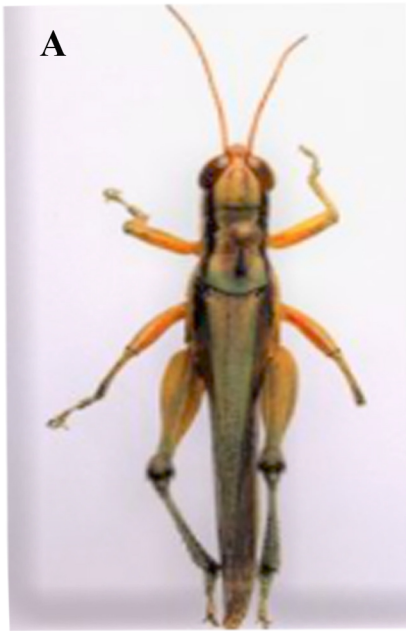


Fig. 1.1. Map of Kerala showing the sampling sites selected for the collection of insects

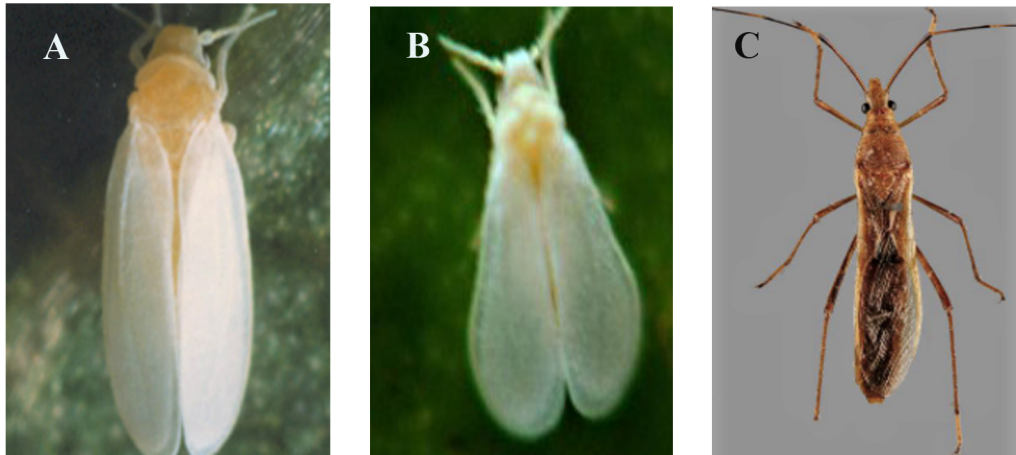


Order Orthoptera: A. *Oxya chinensis* B. *Oxya hyla*



Order Blattodea: C. *Odontotermes feae*, D. *O. obesus*,
E. *Nasutitermes gardneri*

Fig. 1.2. Insect pests screened for the study



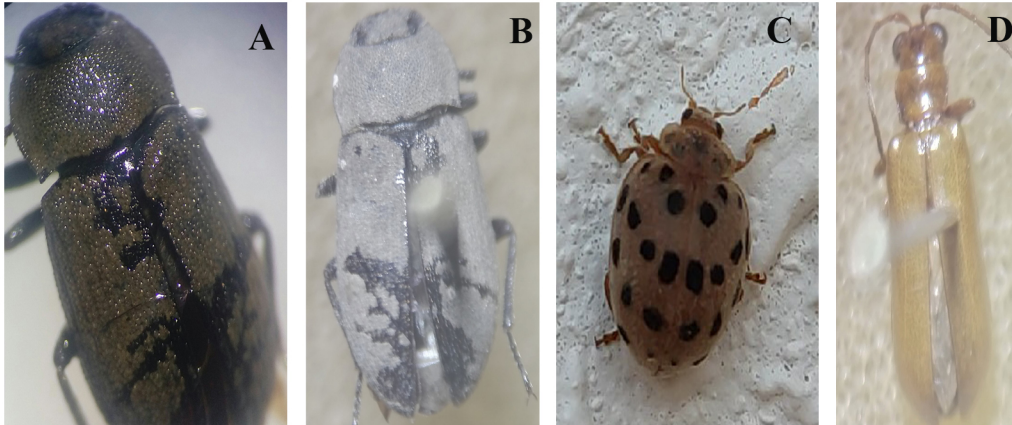
Order Hemiptera: A. *Bemisia tabaci*, B. *Aleurothrixus floccosus*
C. *Leptocorisa acuta*



Order Coleoptera: D. *Altica* sp., E. *Aulacophora foveicollis*,
F. *A. frontalis*, G. *Batocera rufomaculata*



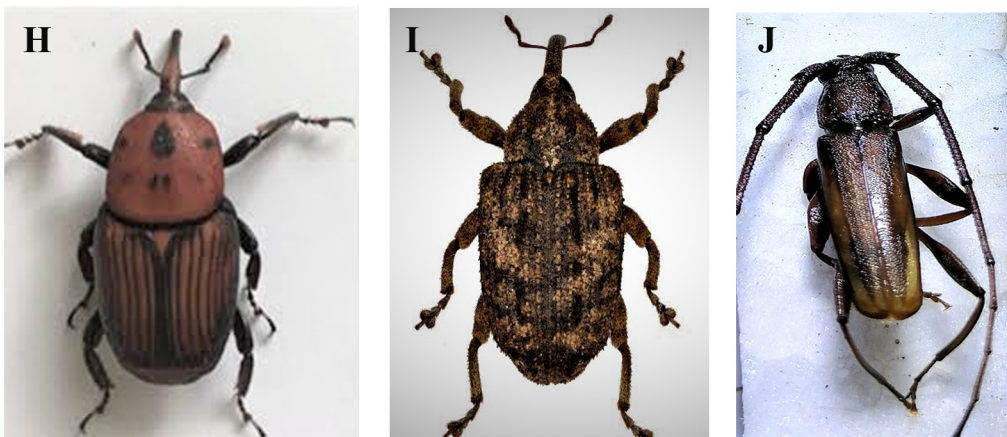
H. *Catharsius molossus*, I. *Copris repertus*, J. *Cosmopolites sordidus*
Fig. 1.3. Insect pests screened for the study



Order Coleoptera: A. *Gonocephalus* sp.1, B. *Gonocephalus* sp.2, C. *Henosepilachna vigintioctopunctata*, D. *Hoplasoma unicolor*

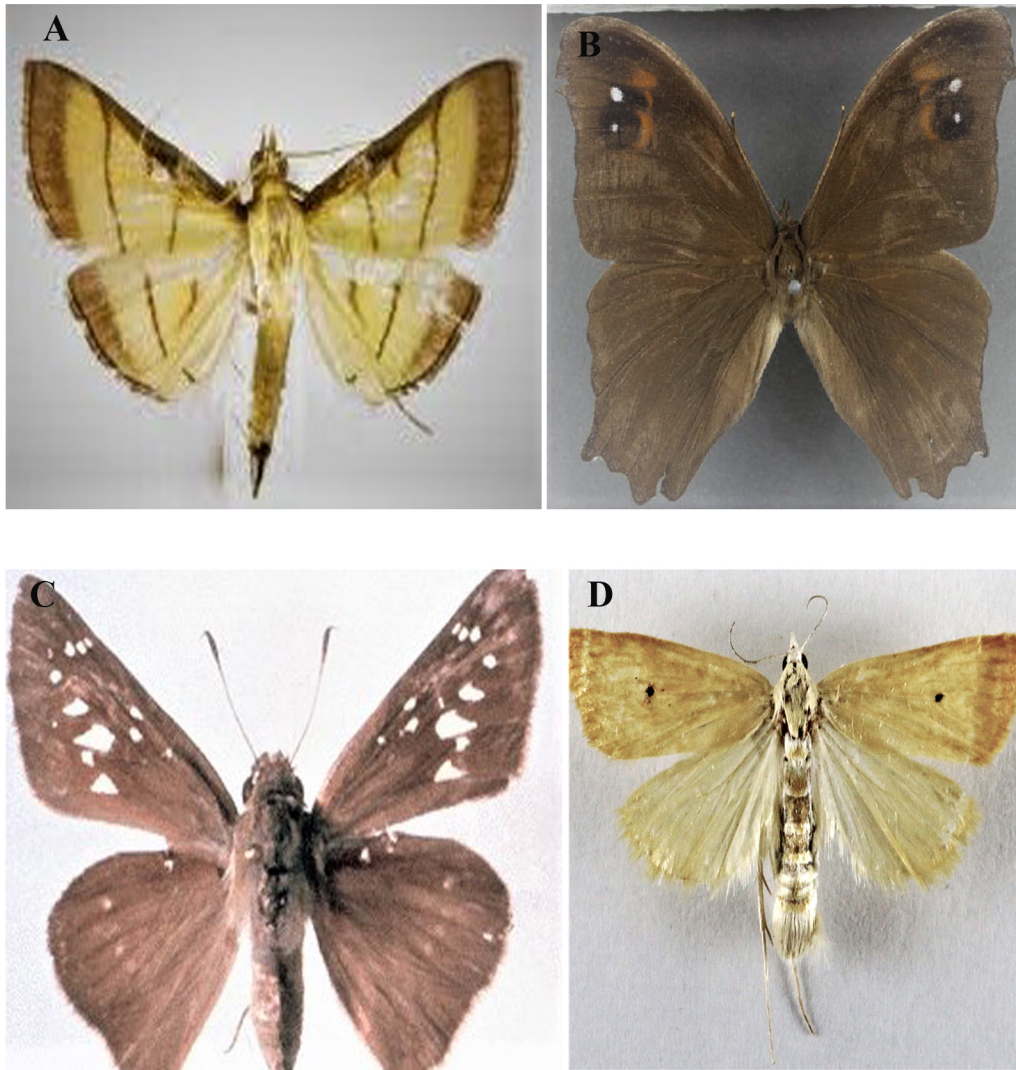


E. *Odoiporus longicollis*, F. *Onitis philemon*, G. *Oryctes rhinoceros*



H. *Rhynchophorus ferrugineus*, I. *Sternochetus mangiferae*, J. *Xystocera globosa*

Fig. 1.4. Insect pests screened for the study



Order Lepidoptera: A. *Cnaphalocrocis medinalis*, B. *Melanitis leda ismene*, C. *Pelopidas mathias*, D. *Scirpophaga incertulas*
 Fig. 1.5. Insect pests screened for the study



Fig. 1.6 . Collection of insects from different fields

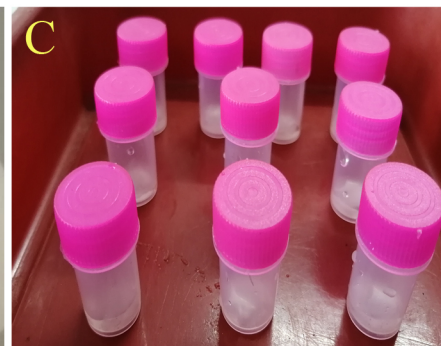


Fig. 1.7 .A. Screw top containers used for checking the necromeny between *Odoiporus longicollis* and *Histiostoma furrowa* sp.nov. B. Decapitated carcass placed on the pseudostem,C.Screw top containers used for carrying out the life cycle experiment of *H. furrowa* sp. nov., D. Maintenance of *Odoiporus longicollis* in the laboratory

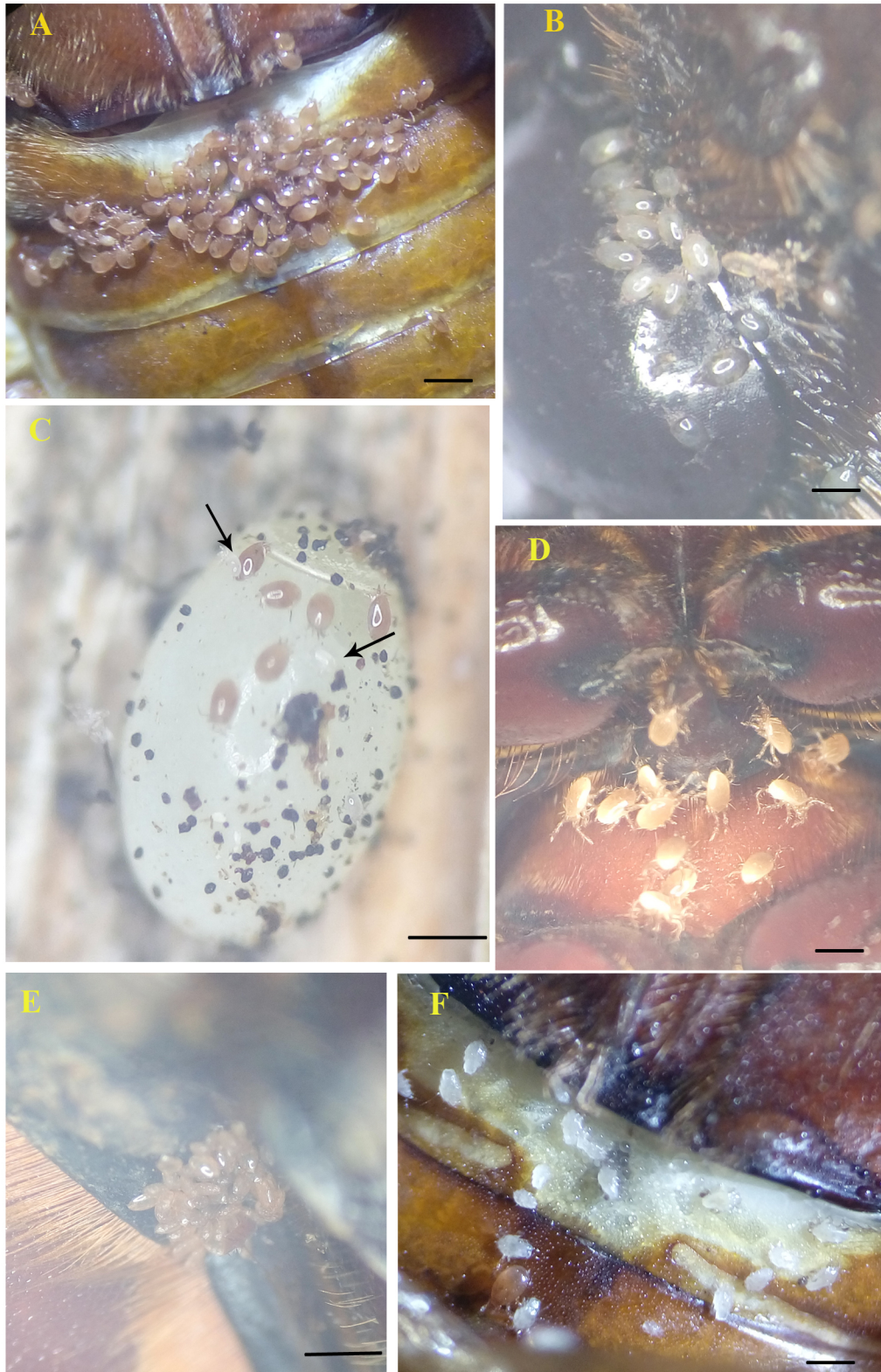


Fig. 1.13 . Mites associated with *Oryctes rhinoceros*. A. *Lasioseius confusus* on abdomen (200 μ m), B. *Sancassania boharti* on hypomeron (200 μ m), C. *Acotyledon tariqi* and *Tyrophagus putrescentiae* (indicated by arrow) on eggs (250 μ m), D. *Hypoaspis sardous* on prosternum (200 μ m), E. *Uropoda heliocopridis* on coxal base (250 μ m), *Athogavia oryctae* sp. nov. on abdomen (200 μ m)

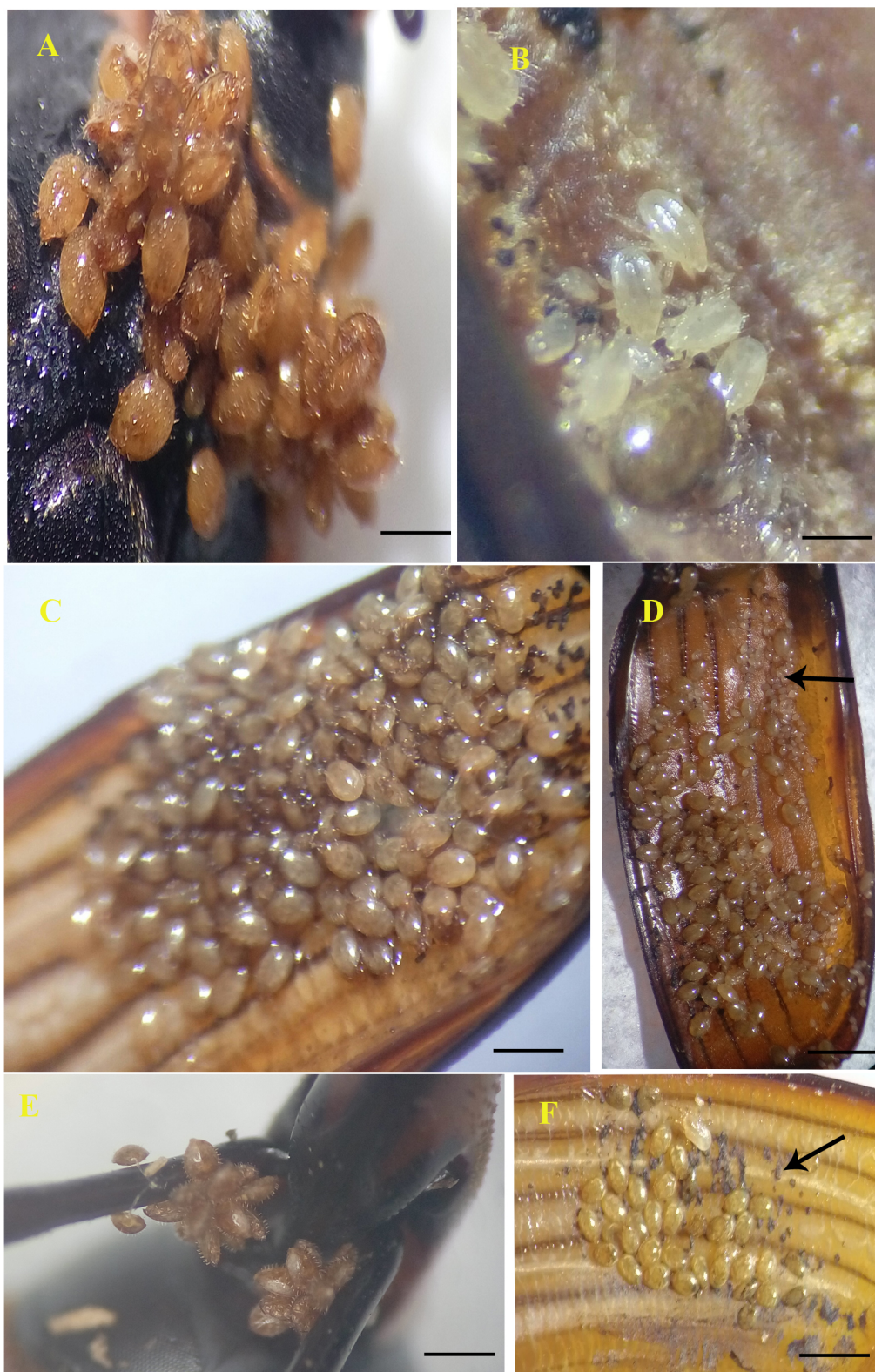


Fig. 1.14. Mites associated with *Rhynchophorus ferrugineus*.
 A. *Uroobovella assamomarginata* on mesoventrite (250 μ m),
 B. *Digamasellus quadrisetus* under elytra (300 μ m),
 C. *Centrouropoda almerodai* under elytra (300 μ m),
 D. *C. almerodai* and *Curculanoetus keralensis* sp. nov. (indicated by arrow) under elytra (250 μ m), E. *Uroobovella javae* on antennae (300 μ m), F. Anal pedicel remains of *C. almerodai* (500 μ m)

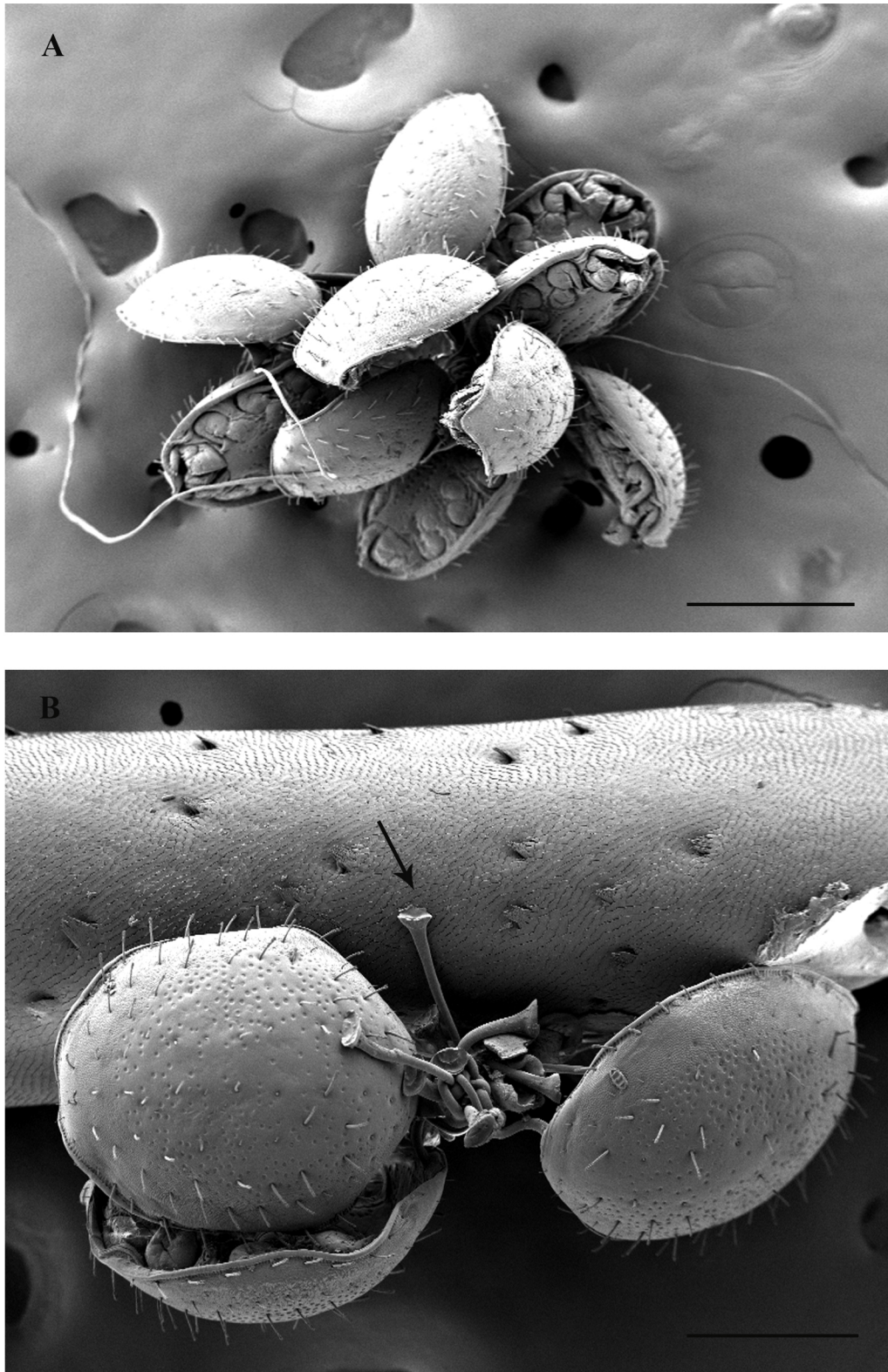


Fig. 1.15 . A. Cluster of *Uroobovella javae*, B. *Uroobovella asamomarginata* on the proboscis of *Rhynchophorus ferrugineus* (Arrow indicates anal pedicel secreted by the deutonymphs). Scale A&B- 200 μ m.



Fig.1.16 . Mites associated with whiteflies. A. *Lasioseius* (*Lasioseius*) *moolamkudensis* sp. nov. with eggs of *Bemisia tabaci*, B. *Amblysieus largoensis* with *Aleurothrixus floccosus*, C. *Eusieus ovalis* with eggs of *Bemisia tabaci*, D. *Amblysieus vasiformis* with eggs of *B. tabaci*. Scale A-D- 300 μm.

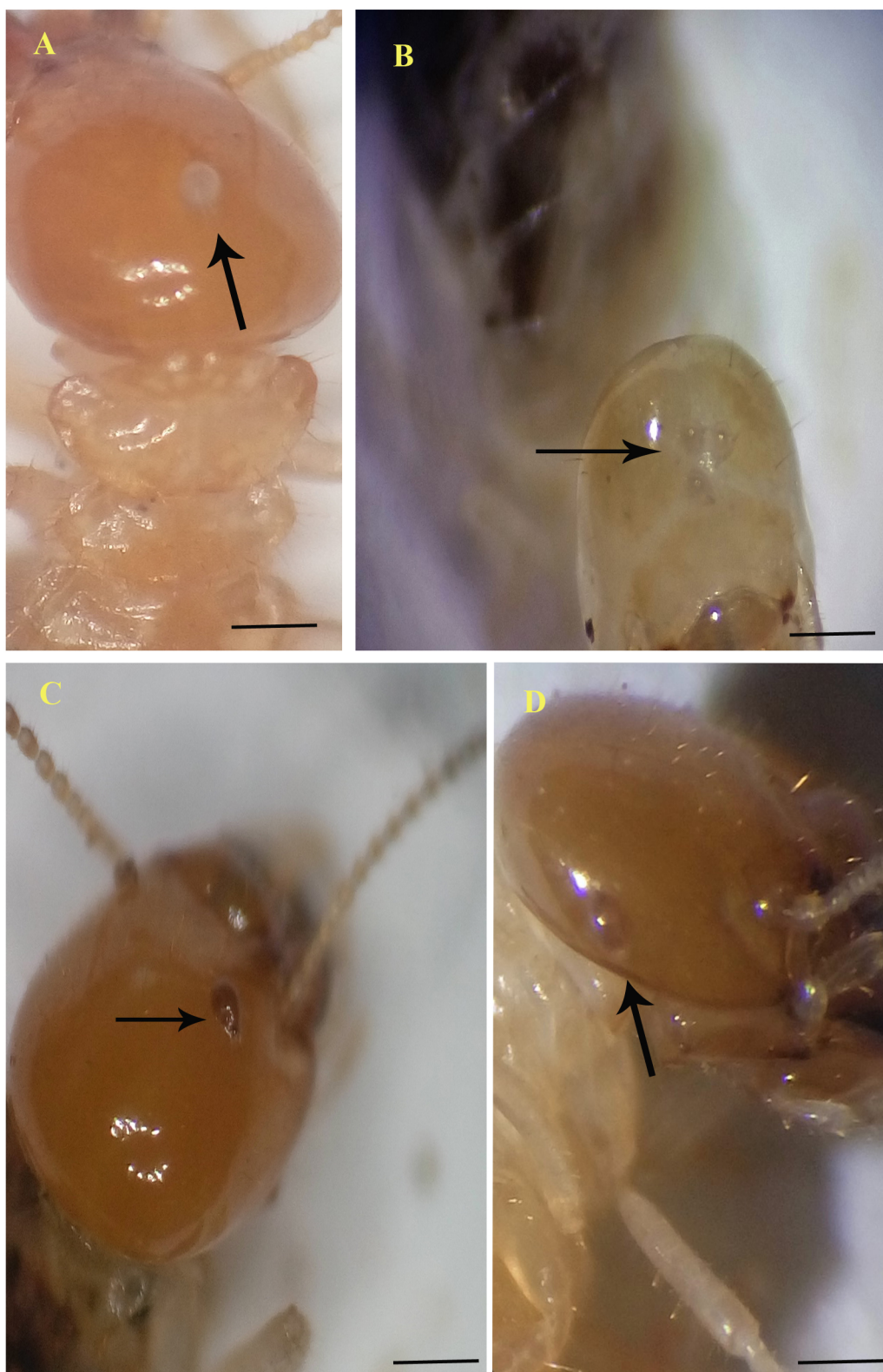


Fig.1.17.Mites associated with termites. A. *Histiostoma herballi* on *Odontotermes obesus*, B. *Acarus solimani* on *Nasutitermes gardneri*, C. *Caloglyphus subterraneusi* on *Odontotermes feae*,D. *Sancassania boharti* on *O. obesus*. Scale A-D- 300 μ m.

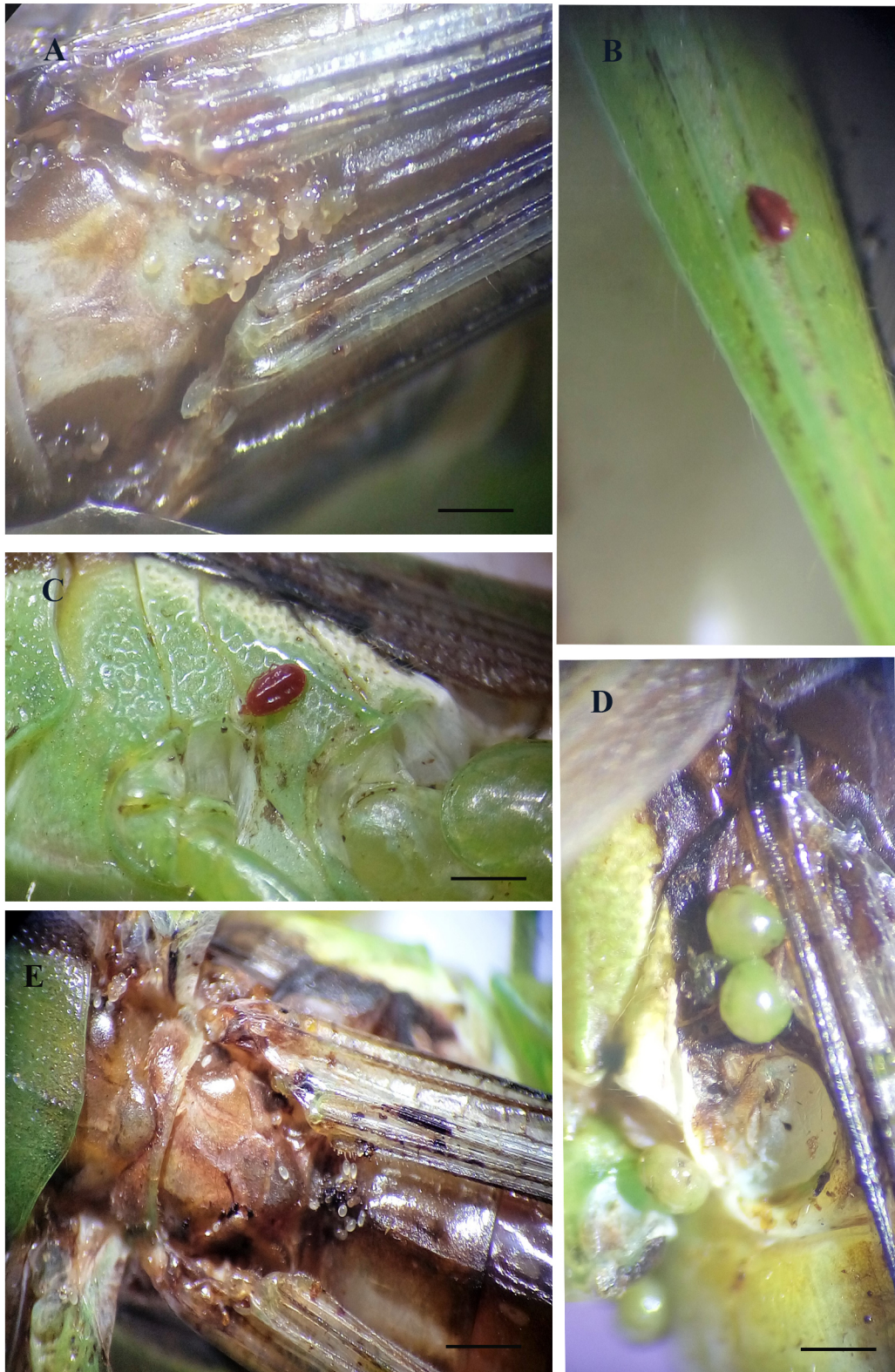


Fig. 1.18 . Mites asociated with *Oxya* spp. A. Stages of *Podapolipus palappuramensis* sp. nov. on *Oxya hyla*, B & C. *Leptus treati* on *Oxya chinensis*, D. Adult female of *P. palappuramensis* sp. nov. on *O. hyla*, E. *Locustacarus chinensis* sp. nov. on *Oxya chinensis*. Scale A-E-300µm.

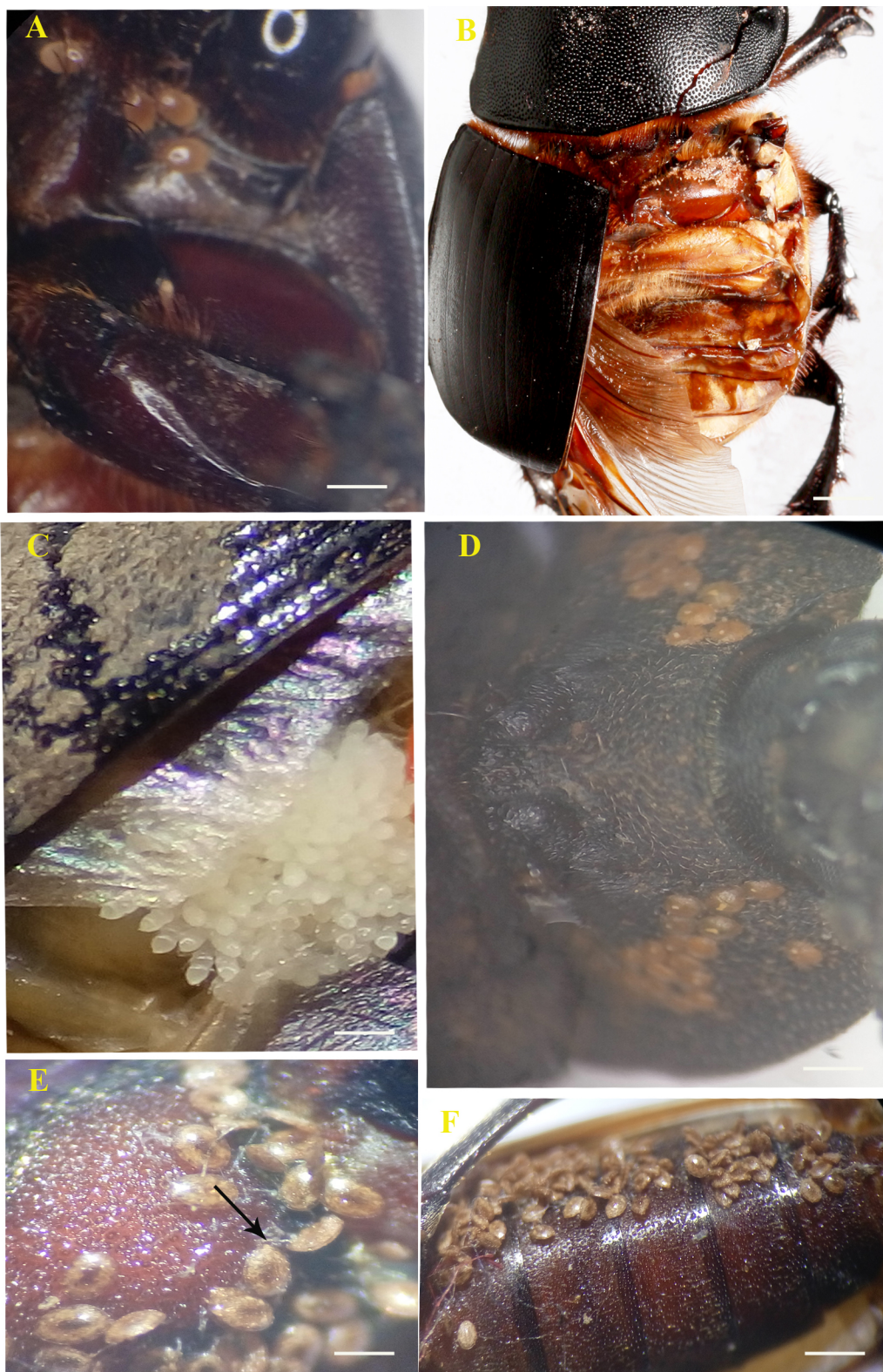


Fig. 1.19. A. *Hypoaspis heselhousei* on *Catharsius molossus*, B. *Pygmephorellus indicus* sp. nov. on *Copris repertus*, C. *Hoplocheylus longispinus* on *Gonocephalus* sp. 2, D. *Cheyletus kuznetsovi* on *Gonocephalus* sp. 1, E. Anal pedicel of *Uropoda shangaica*, F. *Uropoda shangaica* on *Xystocera globosa*. Scale A-F-250 μm.



Fig. 1.20. Mites associated with *Batocera rufomaculata*. A. *Canestriniella batocera* sp. nov. nymphal stage under the elytra, (300 μ m) B. *C. batocera* sp. nov. and *Uropoda orbicularis* (indicated by arrow) under elytra (300 μ m), C. Stages of *C. batocera* sp. nov. on hindwings, (250 μ m) D. *C. batocera* sp. nov. adult on hindwings (500 μ m), E. *Neosilphitrombium gratum* on abdomen (500 μ m)

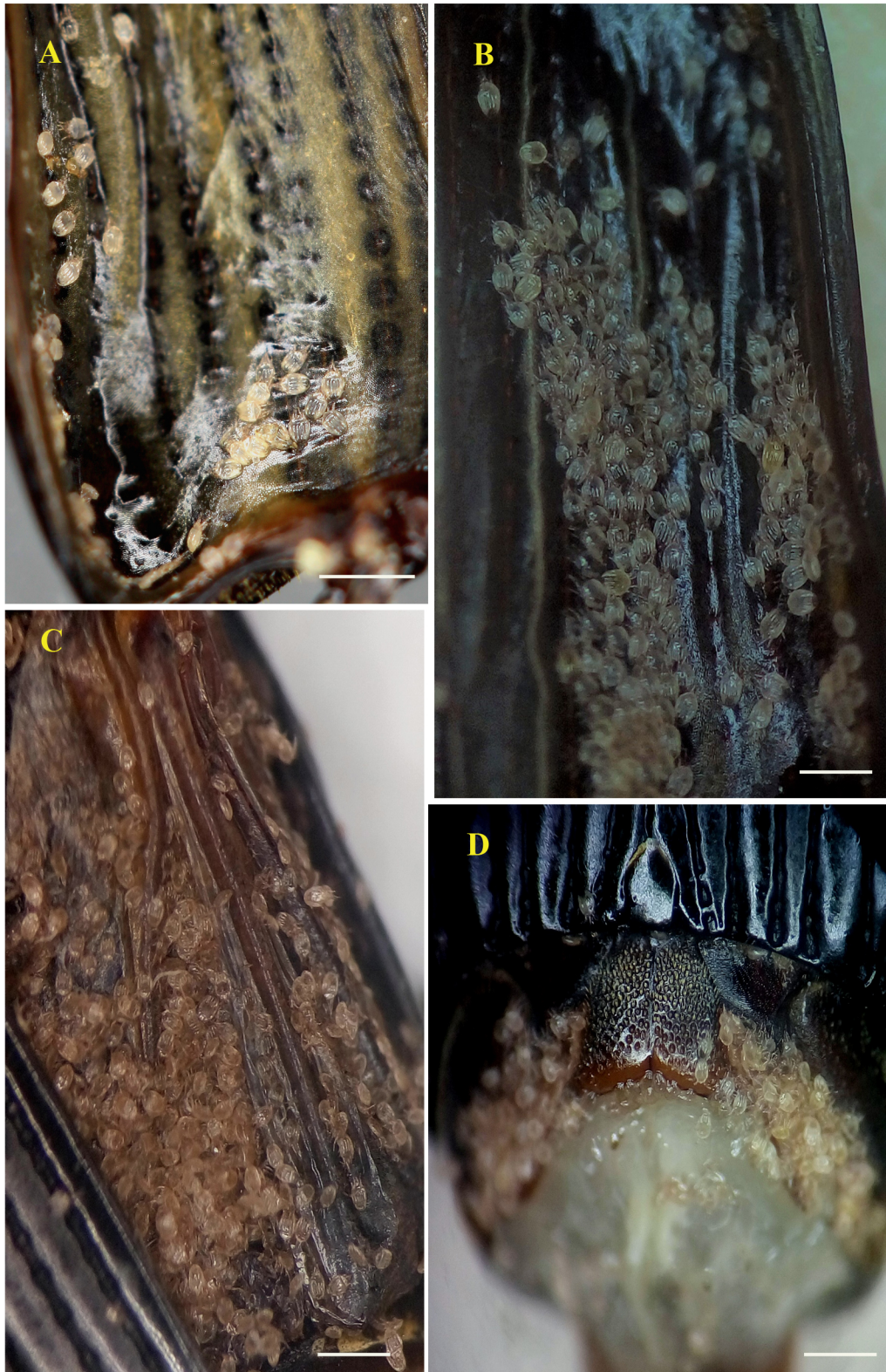


Fig. 1.21. Mites associated with *Odoiporus longicollis*. A & B. *Histiostoma furrowa* sp. nov. under the elytra, C. *H. furrowa* sp. nov. on hindwings, D. *H. furrowa* sp. nov. on the groove anterior to mesosternum. Scale A-D-500 μ m.



Fig. 1.22. Mites associated with leaf beetles. A. *Histiostoma sammari* on *Aulacophora foveicollis*, B. *Procalvolia* sp. on *Hoplasoma unicolor*, C. *Procalvolia* sp. on *A. foveicollis*, D. *Histiostoma sammari* on *Aulacophora frontalis*, E. *Histiostoma maritimus* on *Altica* sp. Scale A-E- 300 μ m.

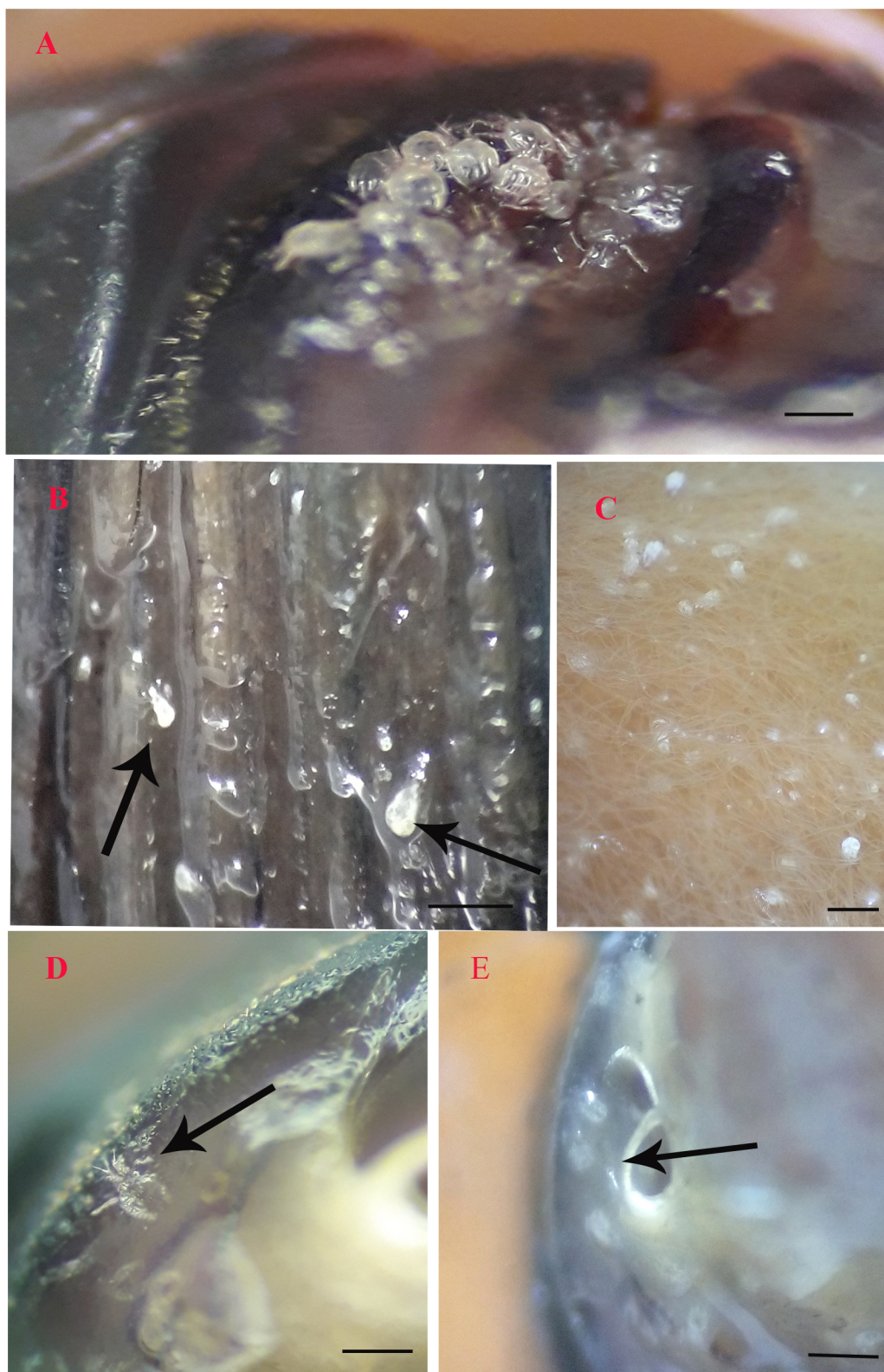


Fig. 1.38. *Histiostoma furrowa* sp. nov. on different substratum. A. Deutonymphs of *H. furrowa* sp. nov. on *Odoiporus longicollis*, B. Adult male and female of *H. furrowa* sp. nov. (indicated by arrow) on pseudostem, C. Different stages of *H. furrowa* sp. nov. on decaying pseudostem, D. Deutonymph of *H. furrowa* sp. nov. about to molt, E. Tritonymphs of *H. furrowa* sp. nov. on the decaying carcass of *O. longicollis*. Scale A-E- 100 μ m.

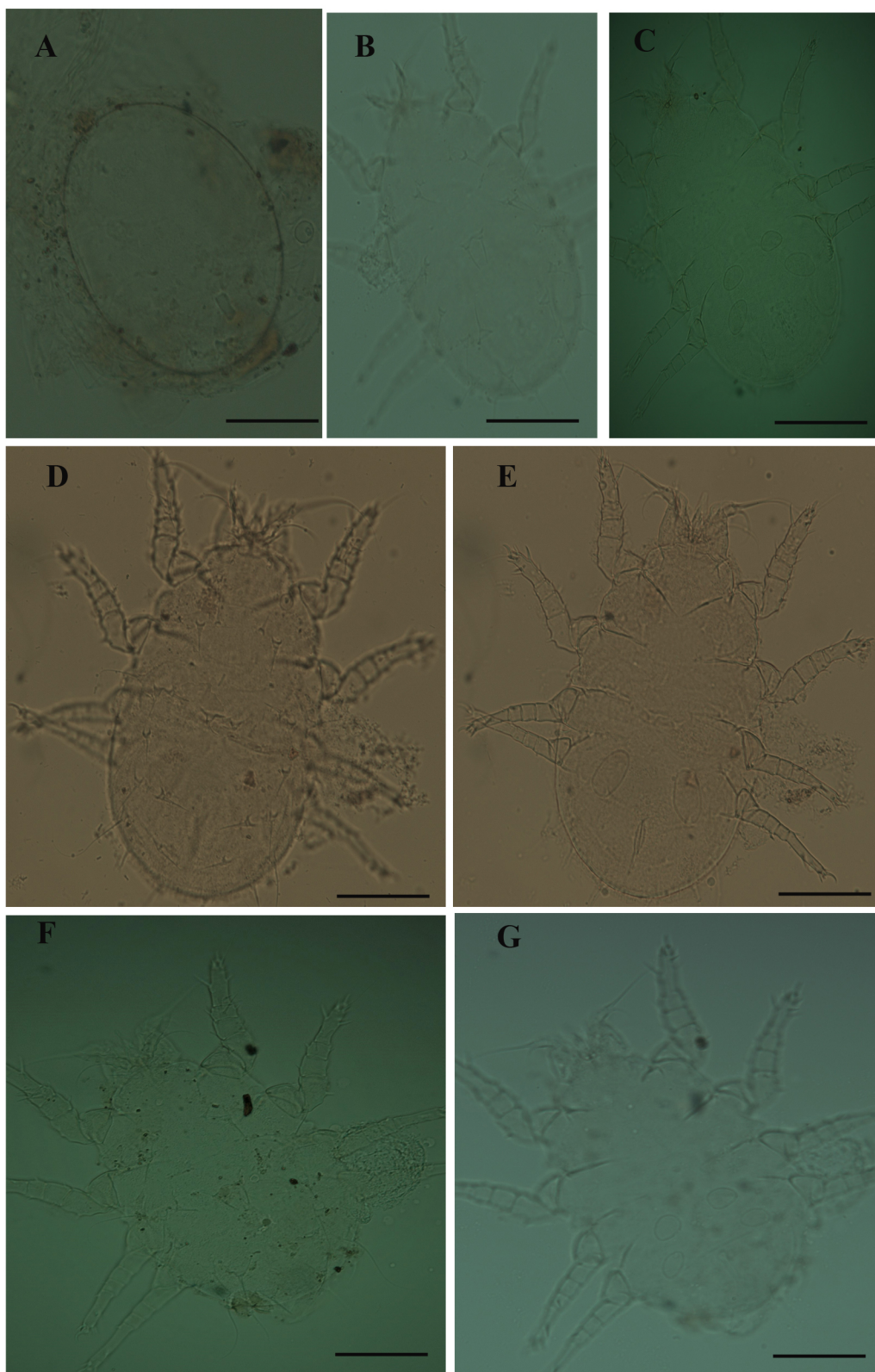


Fig. 1.39. Slide mounts of different life stages of *Histiostoma furrowa* sp. nov. A. Egg, B. Larva (Dorsal), C. Larva (Ventral), D. Protonymph (Dorsal), E. Protonymph (Ventral), F. Tritonymph (Dorsal), G. Tritonymph (Ventral). Scale A-G- 20 μm.

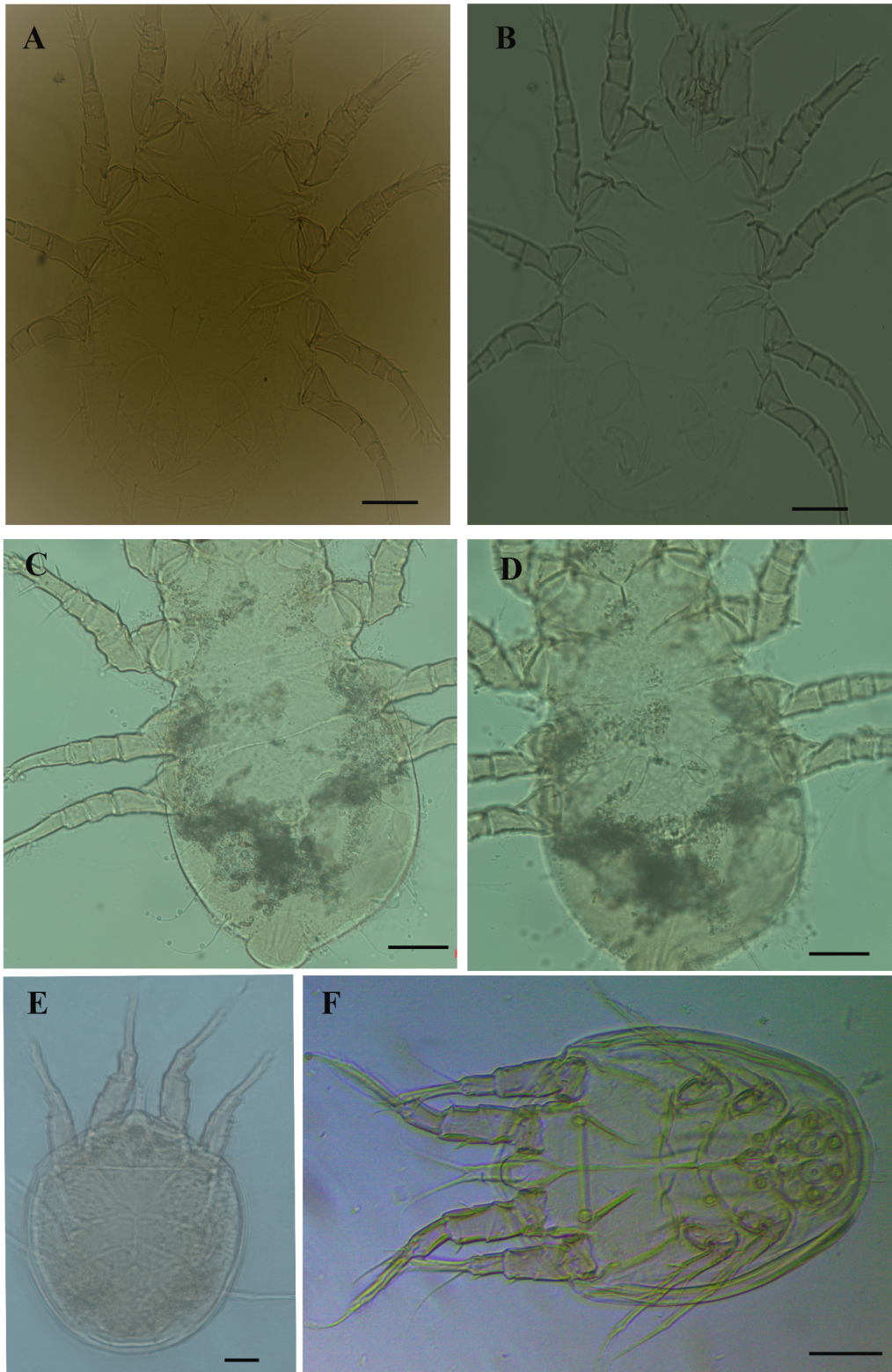


Fig.1.40. Slide mounts of different life stages of *Histiostoma furrowa* sp. nov. A. Adult female (Dorsal), B. Adult female (Ventral), C. Adult male (Dorsal), D. Adult male (Ventral), E. Deutonymph (Dorsal), F. Deutonymph (Ventral). Scale A-F- 20 μm.

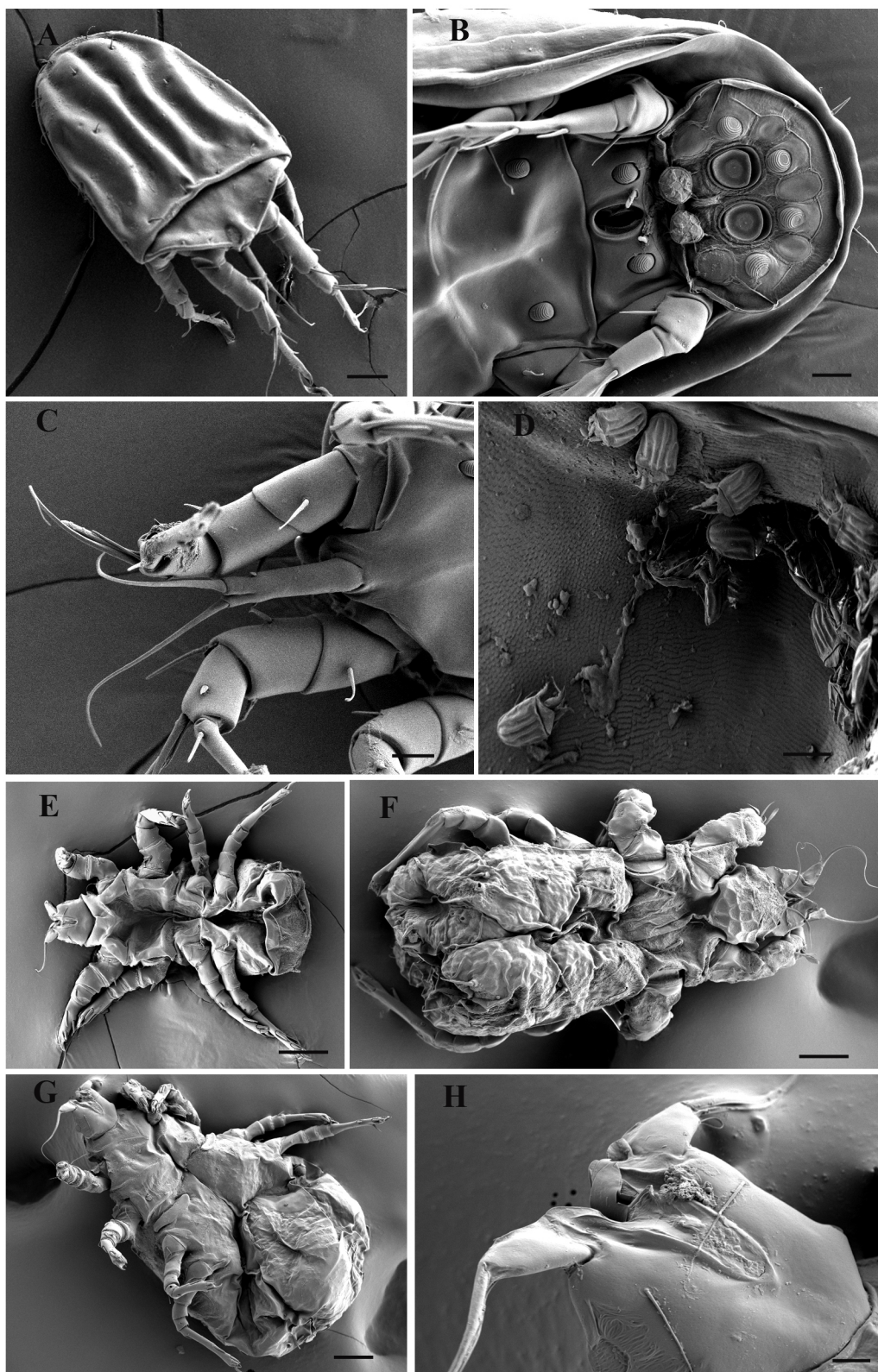


Fig.1.41. SEM image of *Histiostoma furrowa* sp.nov. A.Deutonymph (Dorsal), B.Deutonymph (Ventral), C. Gnathosoma of deutonymph, D. Deutonymphs under elytra, E. Adult male (Dorsal), F. Adult female (Dorsal), G. Adult female (Ventral), H. Gnathosoma of adult. Scale A-C-20 μ m, D-10 μ m, E-G- 20 μ m, H-10 μ m.

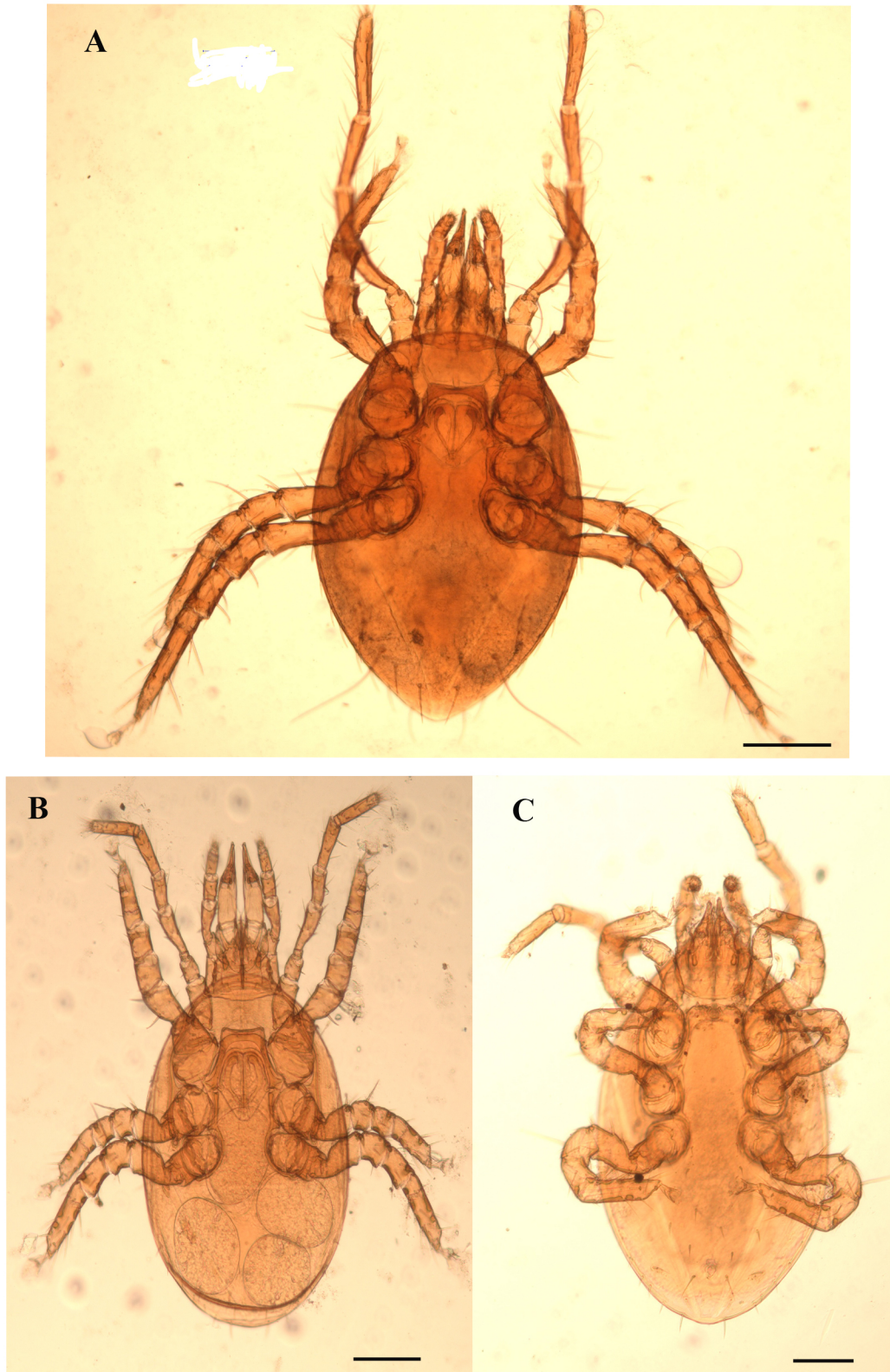


Fig. 1.58. Slide mounts of spp. of the family Diplogyniidae. A. *Tridiplogynium rhynchophora* sp. nov. (Female), B. *Schizodiplogynium rhinocera* sp. nov. (Female), *S. rhinocera* sp. nov. (Male). Scale A-C- 100 μ m.

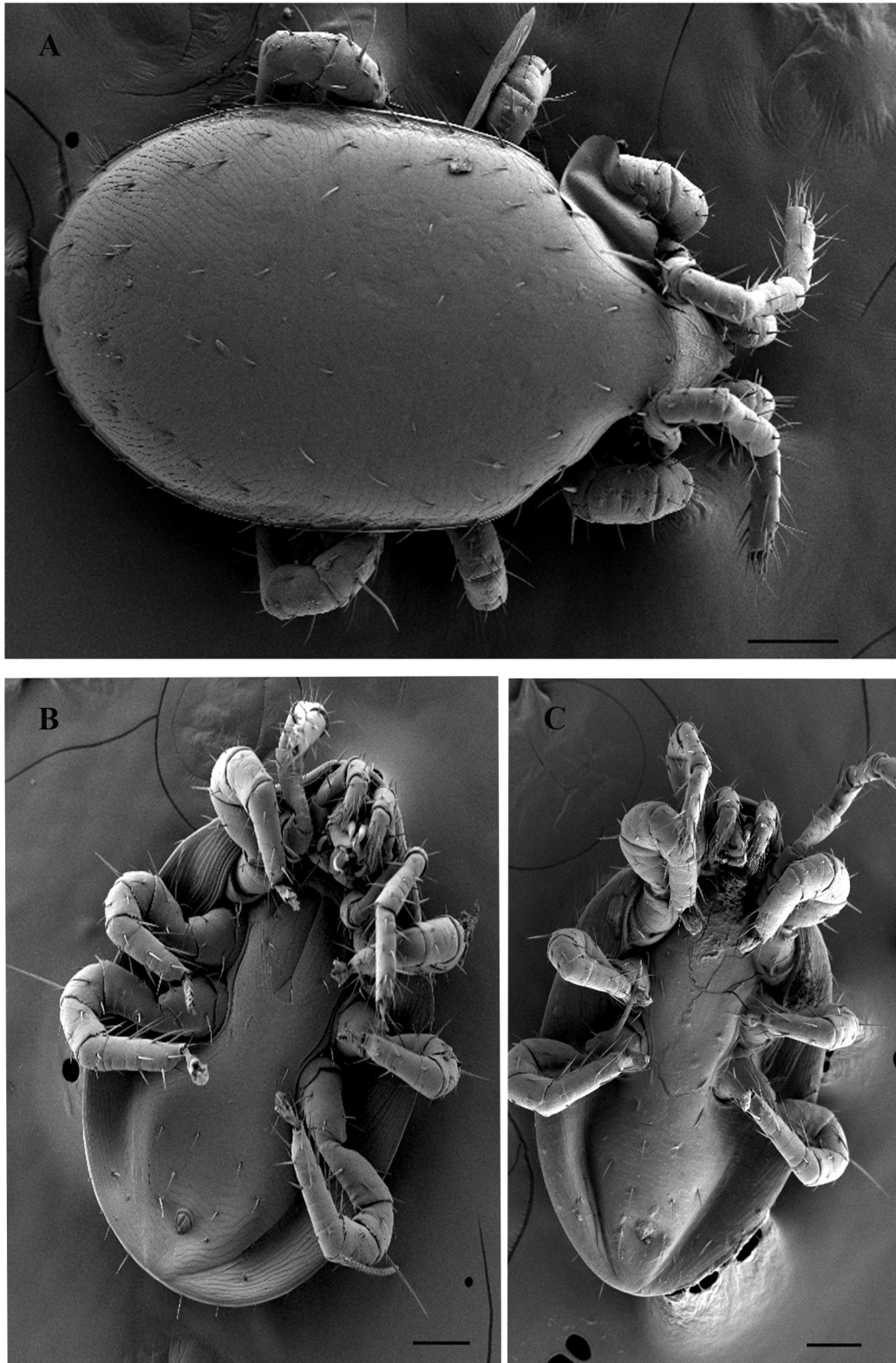


Fig. 1.59. SEM images of A. *Schizodiplogynium rhinocera* sp. nov. (Dorsal), B. *S. rhinocera* sp. nov. (Female Ventral), C. *S. rhinocera* sp. nov. (Male Ventral). Scale A-C- 100 µm.

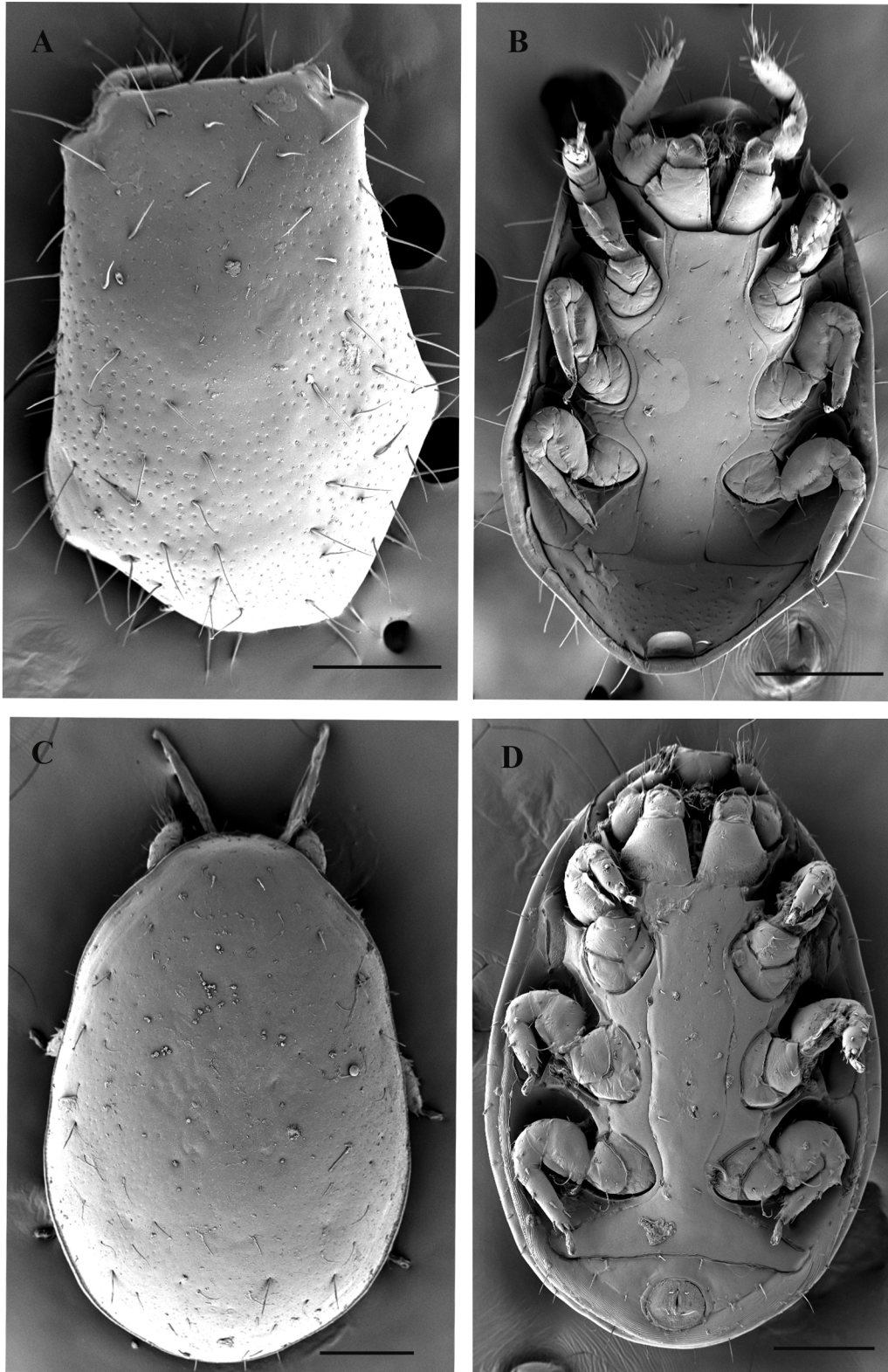


Fig. 1.64. SEM images of A & B. *Uroobovella assamomarginata* (Dorsal and ventral), C & D.. *Centrouropoda almerodai* (Dorsal and ventral). Scale A-D- 100 μm.

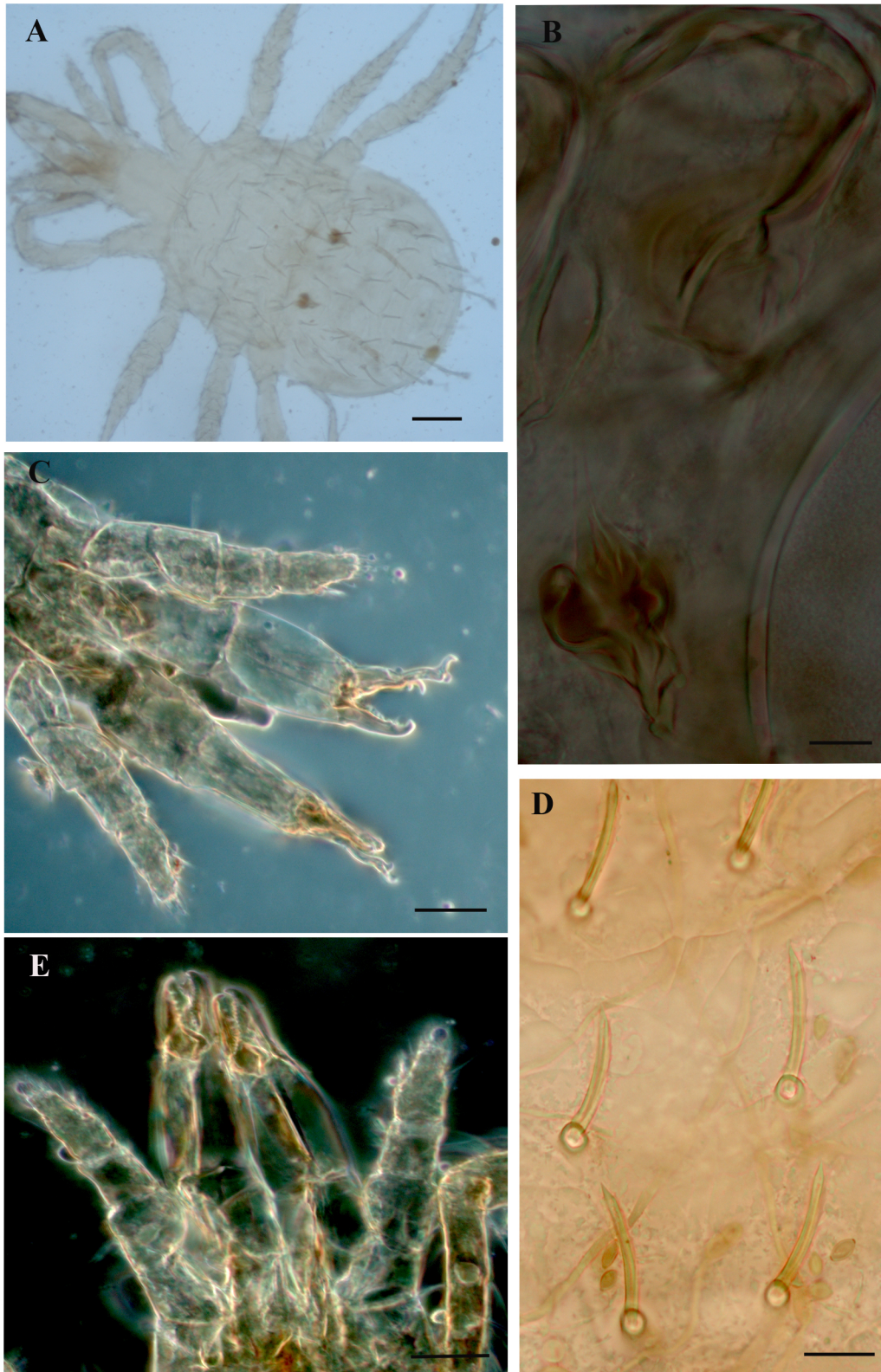


Fig. 1.91. Slide mounts of *Lasioseius (Lasioseius) moolamkudensis* sp. nov.
A. Dorsal, B. Spermatheca, C. Chelicera of male, D. Dorsal setae, E. Chelicera of female. Scale A-10 μm . B-E- 20 μm .

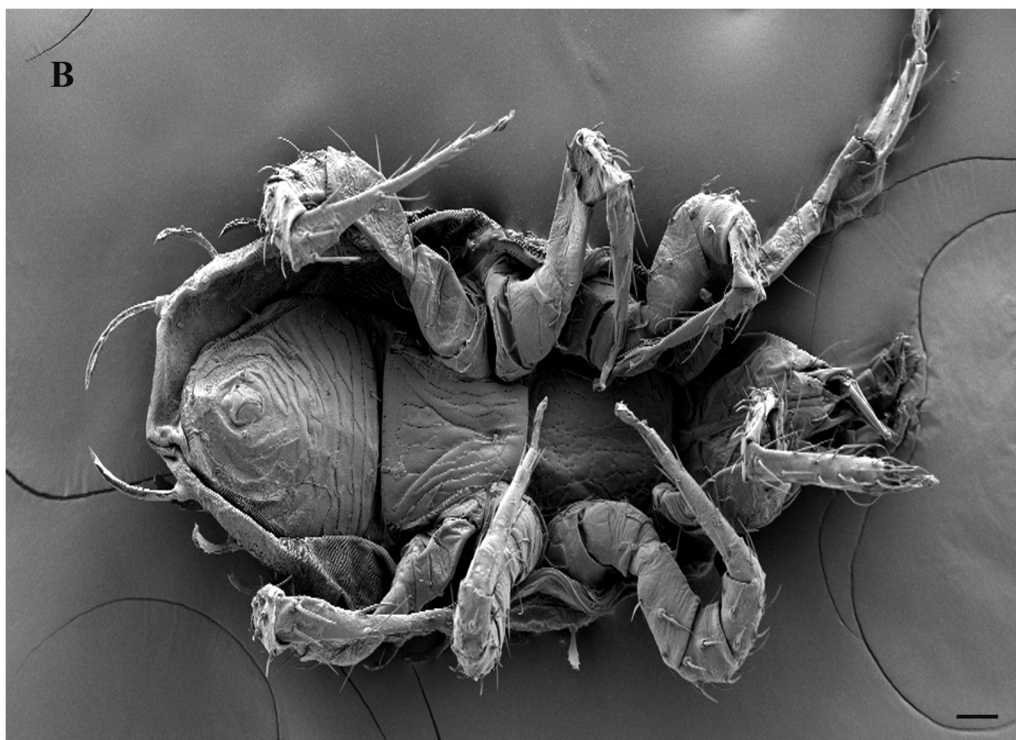
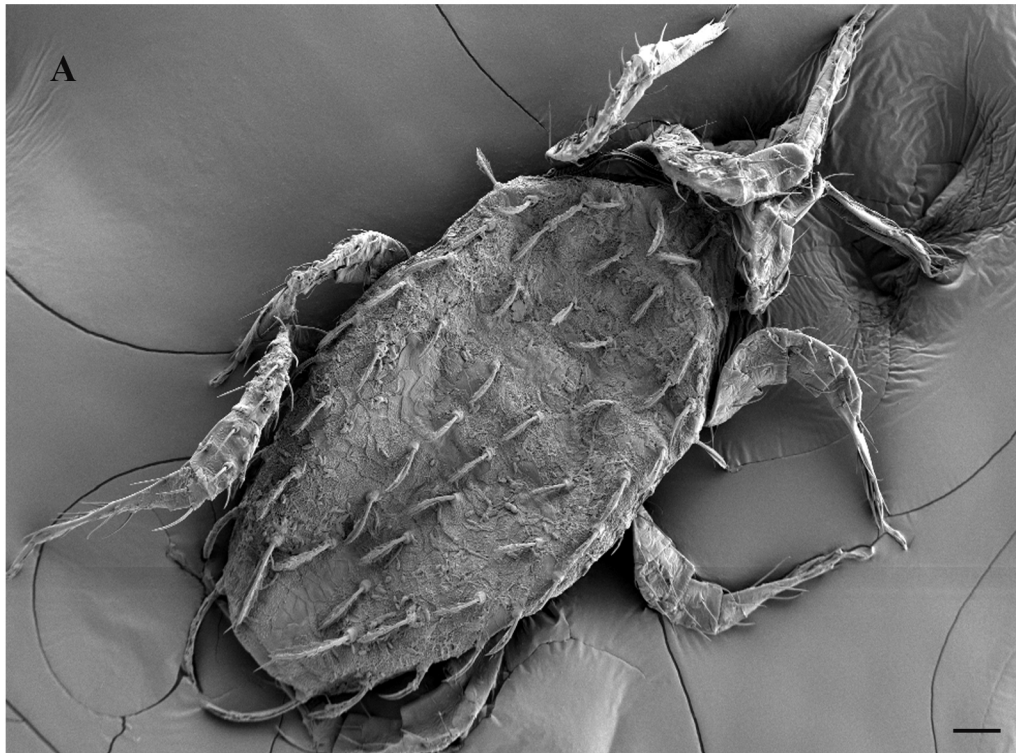


Fig. 1.92. SEM image of *Lasioseius* (*Lasioseius*) *moolamkudensis* sp. nov.
A. Dorsal, B. Ventral. Scale A-B- 20 μ m.

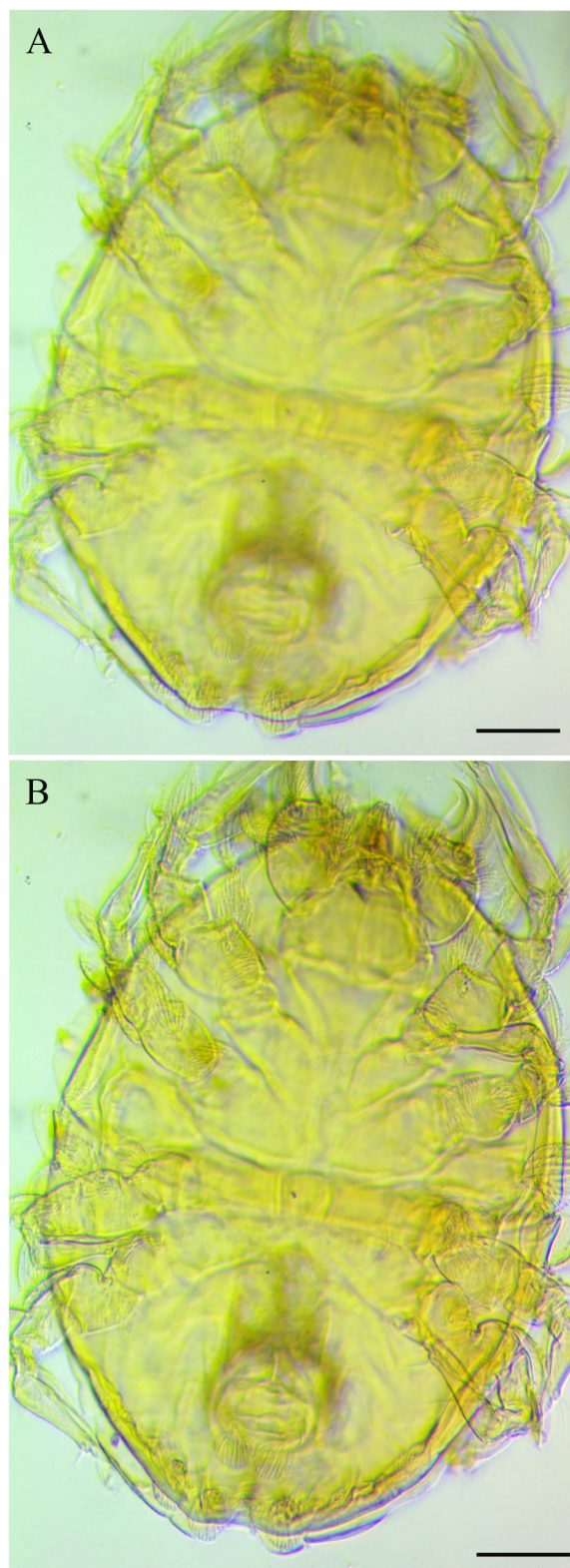


Fig. 1.102. Slide mounts of *Cheyletus kuznetsovi* A. Dorsal, B. Ventral
Scale - 100 μm .

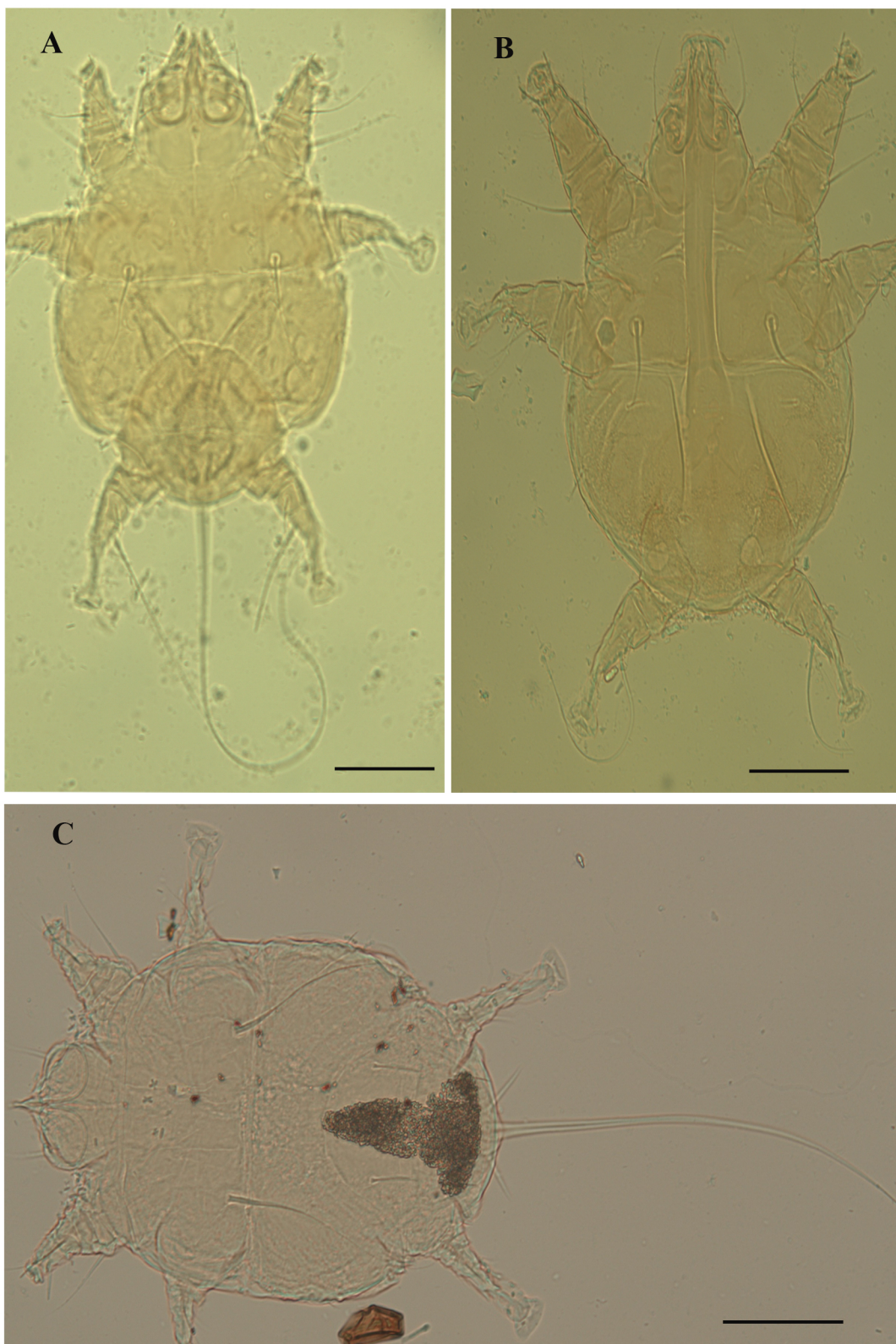


Fig. 1.114. Slide mounts of new species from the family Podapolipidae.
 A. Larval female of *Podapolipus palappuramensis* sp. nov., B. Male of
P. palappuramensis sp. nov., C. Larval female of *Locustacarus chinensis* sp. nov.
 Scale A-C- 50 μ m.



Fig.1.127 Slide mounts of *Curculanoetus keralensis* sp. nov. A. Dorsal, B. Ventral, SEM image of *Curculanoetus keralensis* sp. nov. A. Dorsal, B. Ventral Scale A-D-20 μ m.

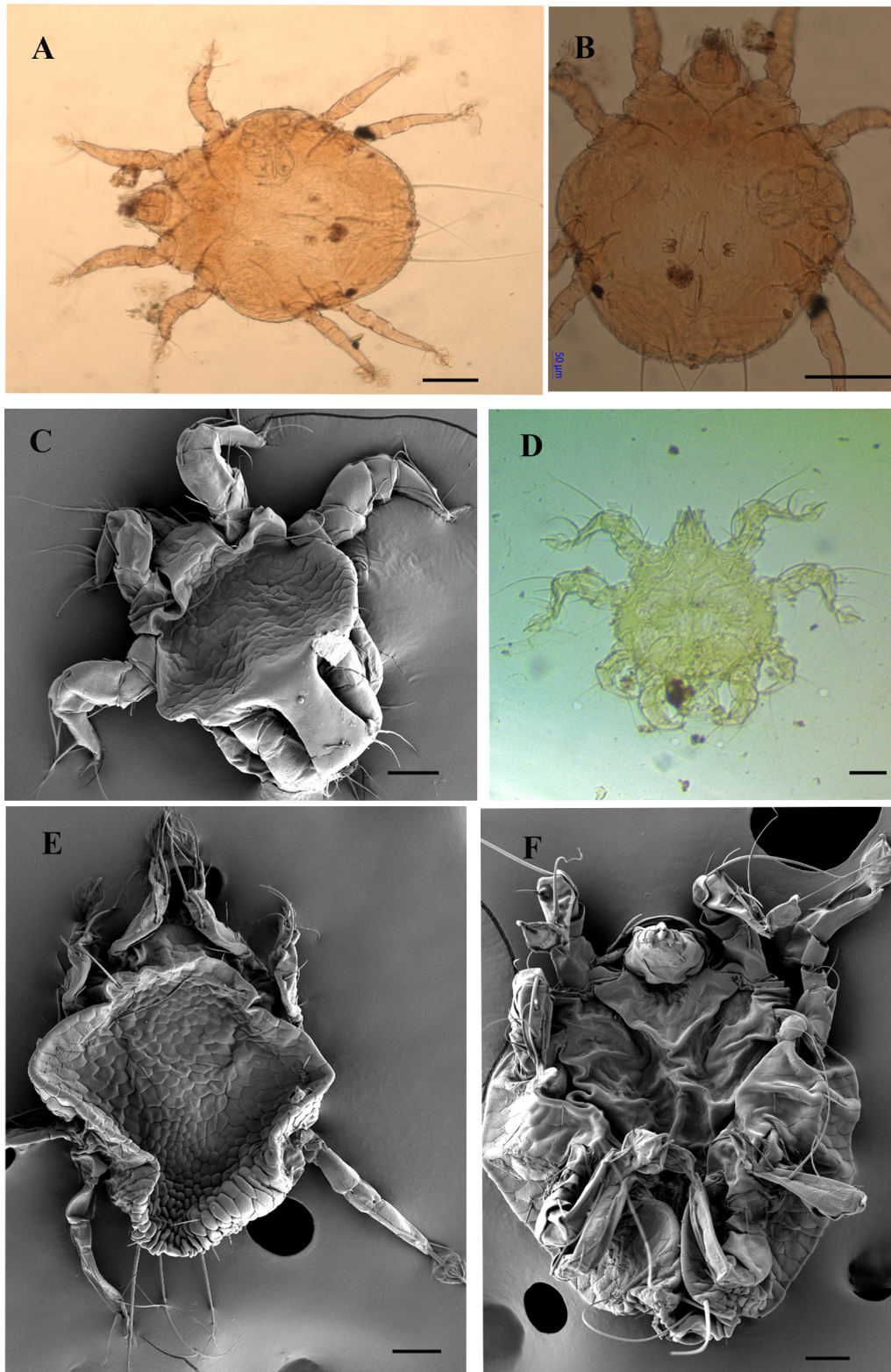


Fig.1.131. Slide mounts and SEM images of *Canestriniella batocera* sp. nov. A. Female (Dorsal), B. Female (Ventral), C. Male (Dorsal), D. Male (Ventral), E. Female (Dorsal), F. Female (Ventral). Scale A-F- 50 μm.

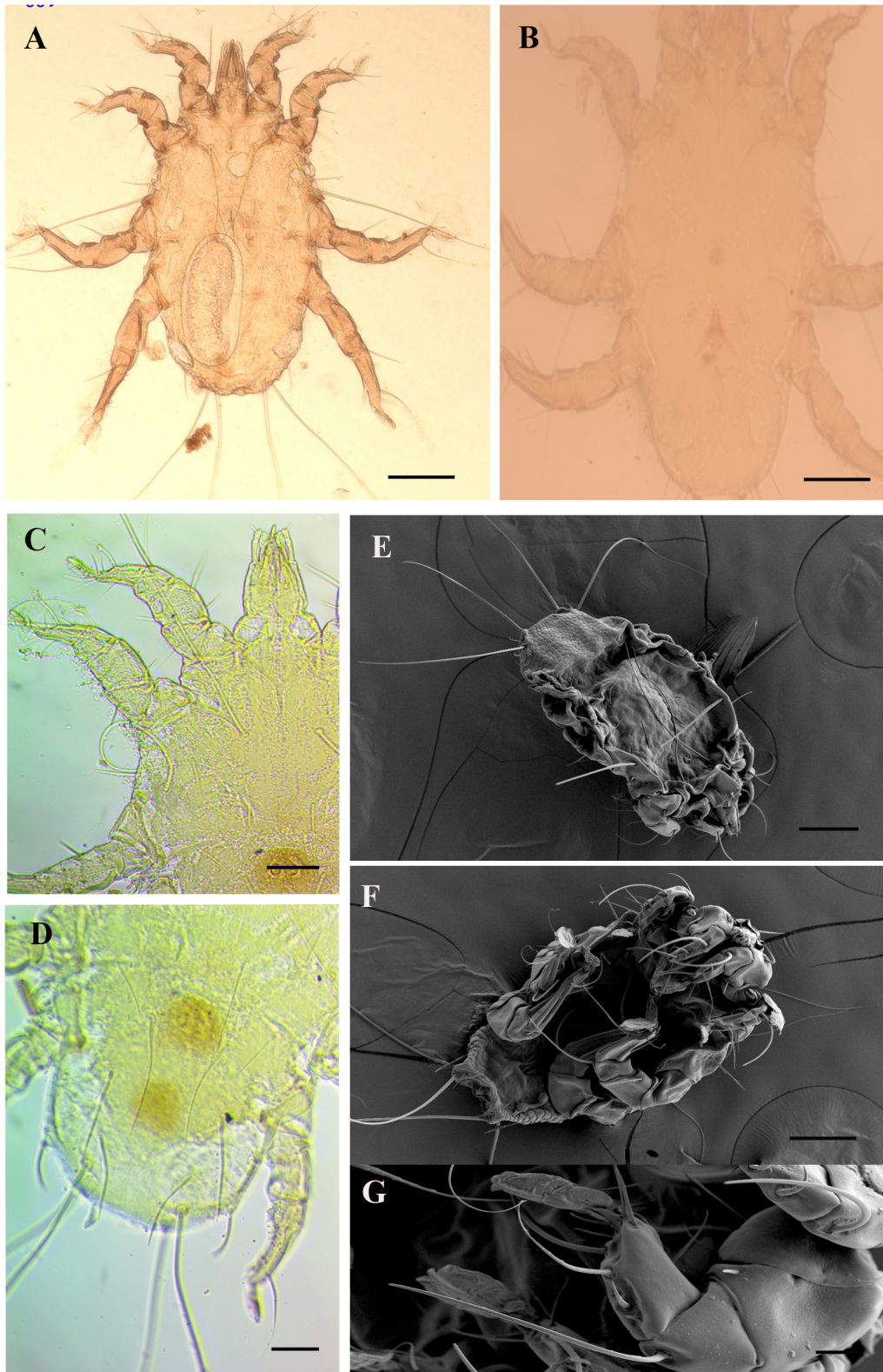


Fig.1.135. Slide mounts and SEM images of *Athogavia oryctae* sp. nov. A. Female (Dorsal), B. Female (Ventral), C & D. Male (Dorsal), E. Female (Dorsal), F. Female (Ventral), G. Legs enlarged. Scale A-G- 100 μ m.



Fig. 2.1. Experimental paddy seedlings maintained for the study of parasitic impact of *Podapolipus palappuramenis* sp. nov. on *Oxya hyla*.

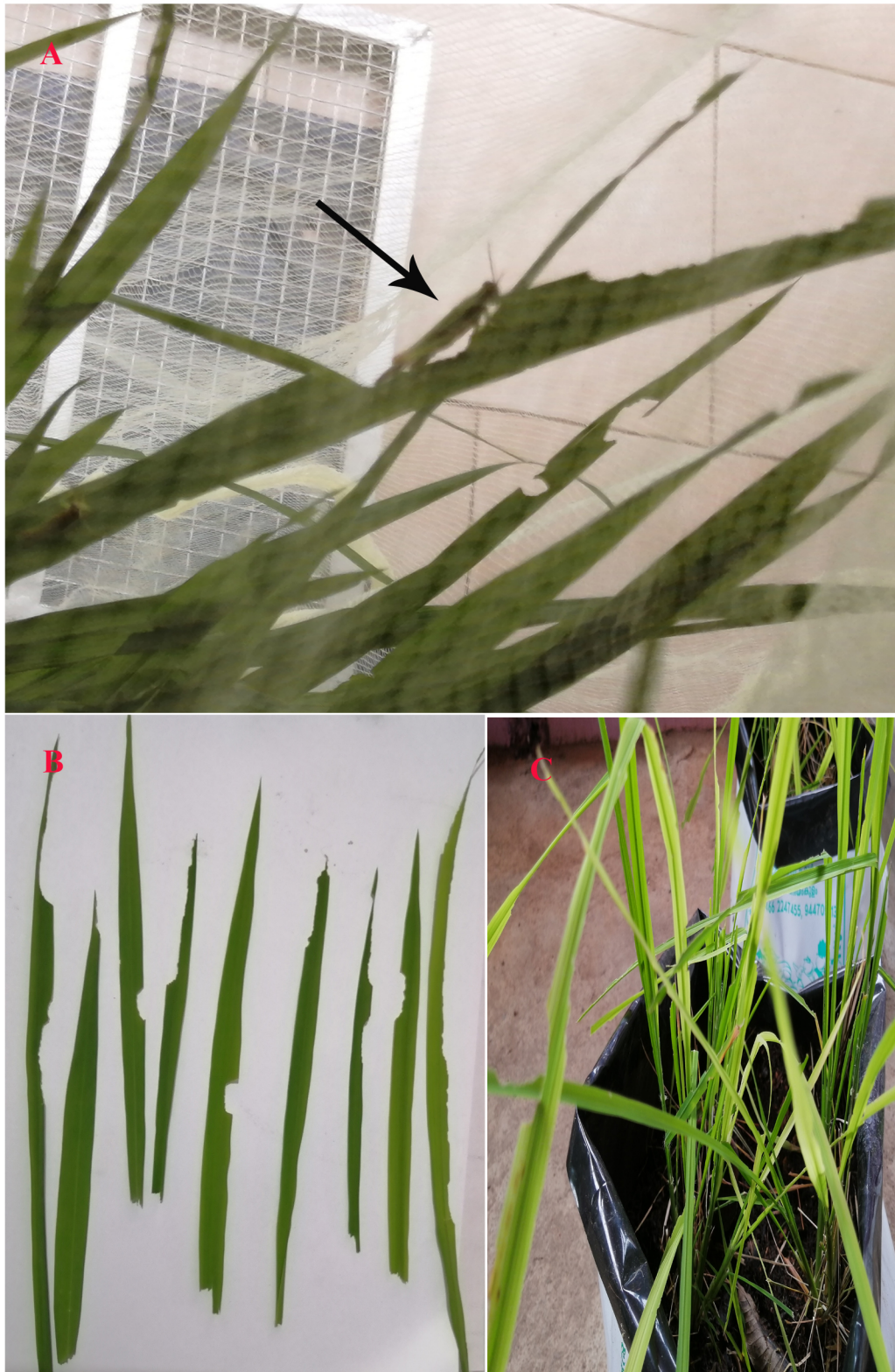


Fig. 2.2. A. *Oxya hyla* feeding on paddy leaves (indicated by black arrow), B. Paddy leaves fed by *Oxya hyla* cut out from plant for the measurement of surface area consumed, C. Paddy damaged by the feeding activity of *Oxya hyla*.



Fig. 2.3. Local varieties of chilly, *Capsicum frutescens* A. LV1, B. LV2, C. LV3, D. LV4, E. LV5, *Capsicum annuum* F. LV6

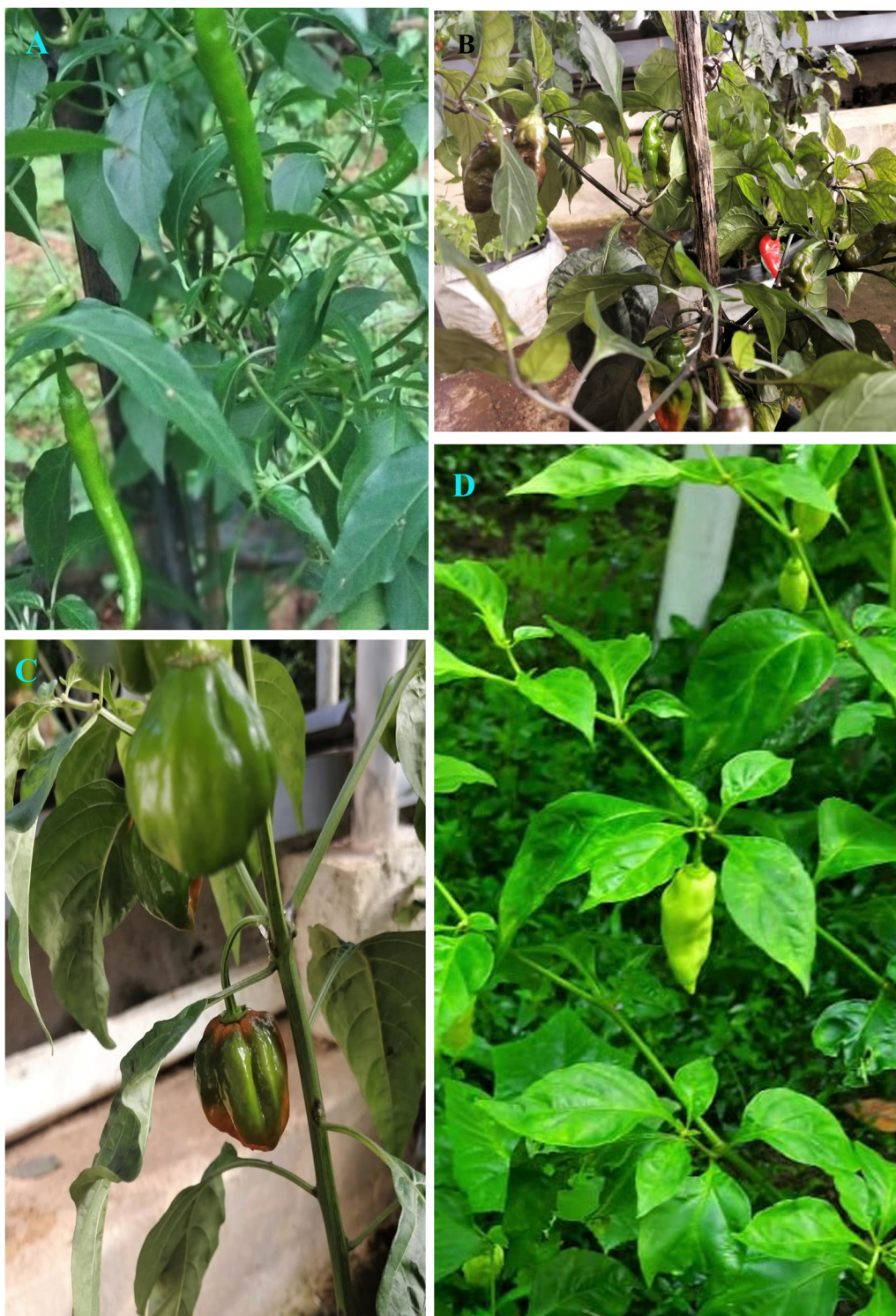


Fig. 2..4. Local varieties of chilli. *Capsicum annuum* A.LV7, B. LV8, C. ,LV9, D. LV10.



Fig. 2.5. A. 1*1 centimeter square window for counting hairs in domatia, B. A well developed chilli leaf domatia (20 μ m).



Fig. 2.6. A. Chilli plant maintained for the supply of whiteflies and predatory mites, B & C. Experimental arena for the assessment of predatory potential of *Lasioseius moolamkudensis* on *Bemisia tabaci*, D. Chilli plants maintained for experiment, E. Whitefly infested chilli



Fig. 2.9. A, B and C- types of chilli leaf showing different types of vein junctions, D. Predatory mites housed inside the leaf domatia of chilli leaf, E. Eggs of predatory mite laid on trichomes of leaf domatia. Scale A-E- 50 μ m.

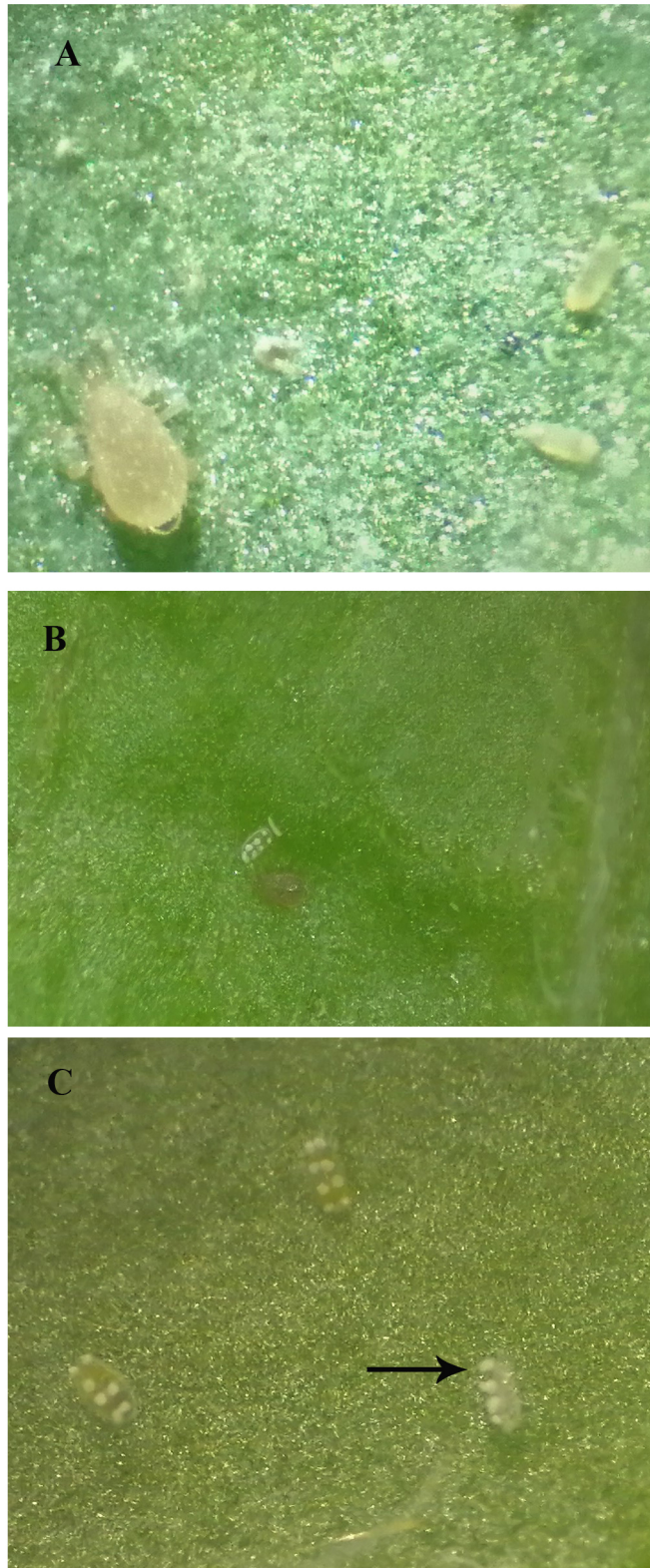


Fig. 2.10 . A. *Lasioseius (Lasioseius) moolamkudensis* sp. nov. with eggs of *Bemisia tabaci*, B. *L. (L.) moolamkudensis* sp. nov. with nymph 2 of *B. tabaci*, C. Nymph 2 of *B. tabaci* (cuticle of nymph 2 left by the predator indicated by black arrow)